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OF THE

INSTITUTION OF
ELECTRICAL ENGINEERS,

INCLUDING

ORIGINAL COMMUNICATIONS ON TELEGRAPHY AND ELECTRICAL SCIENCE.

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JOURNAL

OF THE

Institution of Electrical Engineers.

Founded 1871. *Incorporated* 1883.

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The Three Hundred and Eightieth Ordinary General Meeting was held at the Institution of Civil Engineers, Great George Street, Westminster, on Thursday evening, November 13, 1902—Mr. J. GAVEY, Vice-President, in the Chair.

The minutes of the Annual General Meeting held on May 22, 1902, were read and confirmed.

The CHAIRMAN: Gentlemen, I have an announcement to make which I am sure will be received with a universal expression of regret. We all met here to-night in the hopes of hearing a most attractive and instructive address from our President, but the Council has been advised that he is too ill to appear. The question as to whether the reading of his address should be dealt with by deputy to-night, or whether it should be postponed until the President himself could be present, has been fully considered. Mr. Swinburne, in order to prevent any feeling of disappointment, was rather anxious that it should be read by deputy, but the Council, after giving the question the most earnest consideration, came to the conclusion that the reading of the Presidential address in the President's absence would be something like the play of *Hamlet* with Hamlet left out, and it determined to postpone the reading of the address to some date to be fixed hereafter. I am sure you will all unite with me in expressing the feeling of regret at the attack of illness from which our President is suffering, an attack which I venture to hope is not a dangerous one, although sufficiently serious to incapacitate him from being present this evening. I ask you to authorise the Secretary to advise Mr. Swinburne that the members here present unite with the Council in an expression of regret at his unavoidable absence.

The names of new candidates for election into the Institution were announced, and it was ordered that their names should be suspended in the Library.

The following transfers were announced as having been approved by the Council:—

From the class of Associate Members to that of Members—

G. W. Green.	A. H. Shaw.

From the class of Associates to that of Members—

Capt. H. B. Jackson.	J. W. Leyshon.

F. S. Pilling.

From the class of Associates to that of Associate Members—

W. F. Bruce.	James Nicolson.
J. E. Dawson.	J. G. Scott.
G. L. Eynon.	E. M. Sellon.
Ll. L. Foster.	Percy Speedy.
R. W. Hammond.	James Whitcher.

From the class of Students to that of Associates—

R. D. T. Alexander.	J. W. Griggs.
J. Bentley.	R. P. Howgrave-Graham.
H. E. Britton.	G. W. Mayne.
E. Brown.	C. H. Millar.
J. F. Caine.	T. Normoyle.
H. H. Clements.	H. A. Pearson.
M. A. Codd.	J. St Vincent Pletts.
A. M. Coombs.	H. K. Rodwell.
W. A. Del Mar.	T. G. Smith.
W. H. Derriman.	A. Sommerville.
P. A. Fisher.	L. Vignoles.
P. Good.	A. R. Walmsley.

E. V. Watson.

Donations to the *Library* were announced as having been received since the last meeting from Messrs. Alby, The Astronomer Royal, Cassell & Co., "Colliery Guardian," H. Cuénod, Editor of "Electricity," Institute of Mining Engineers, International Engineering Congress, Glasgow, 1901; E. Jona, Maschinenfabrik Oerlikon, Meteorological Society, B. H. Morgan, Patent Office, R. E. Peake, Royal Society, Rev. G. H. Staite, Teknisk Forenings Tidskrift, W. P. Thompson, Prof. Wyssling, and from Dr. H. Wilde, F.R.S., Honorary Member; Messrs. C. Bright, E. Danvers, L. W. de Grave, J. J. Fahie, B. T. Ffinch, R. K. Gray, Dr. Alfred Hay, W. P. Maycock, J. W. Meares, G. D. A. Parr, Members; and L. Birks, Associate Member; to the *Building Fund* from Messrs. H. O. F. Bindemann, B. G. Burgess, A. J. Cridge, W. P. Digby, H. W. W. Dix, L. Drugman, S. Evershed, The Finsbury Technical College Engineering Society, G. Johnson, J. Kynoch, C. H. McCarthy-Jones, J. C. Matthews, C. F. Proctor, H. M. Sayers, E. S. Shoults, H. D. Symons, F. H. Webb; and to the *Benevolent Fund* from Mr. F. H. Medhurst, to whom the thanks of the meeting were duly accorded.

The CHAIRMAN: I have very great regret in announcing that several deaths have occurred since our last Session. Amongst them are those of Sir Frederick Abel, who was elected a member in 1871, and President in 1877, and who has been a trustee since 1887; Dr. John Hall Gladstone, elected a member in 1873, and a member of Council in 1887; and Professor Sidney H. Short, elected a member in 1901, and a member of the Sectional Committee on Traction, Light, and Power Distribution during 1901 and 1902. I have no doubt that the members will sympathise very heartily with the friends of these gentlemen, most of whom have for so long been associated with us.

APPOINTMENT OF NEW HON. TREASURER.

I have another announcement to make which I feel sure will be received with considerable regret by all our members. Our Honorary Treasurer, Professor W. E. Ayrton, who has held office for so long a time in various capacities, has felt himself compelled, partly owing to ill-health and partly to the pressure of other duties, to resign his office of Honorary Treasurer. We all know our dear and respected friend Professor Ayrton. He was one of our very early members, and we have followed his career with interest and best wishes. We know what erudition he has brought to bear on our debates, and what a useful member he has been to our Institution. He has also devoted a vast amount of time and attention to the interests of the Institution, both at the Council and Committee Meetings, and as Honorary Treasurer. Many of you who have not served in these offices will, in a later period of your lives, when called upon to help to direct the destinies of an Institution of this sort, perhaps appreciate more fully than may now be the case, the amount of work and the sacrifice of valuable time that is necessary in order to carry to a successful issue the affairs of our Institution. I feel sure that you will all unite in a very hearty vote of thanks to Professor Ayrton for the lengthy and honourable service that he has rendered to the Institution.

The vote was carried by acclamation.

The CHAIRMAN: Gentlemen, a very old adage, *Le roi est mort, vive le roi*, applies in this instance as in most others. I am happy to announce that Mr. Robert Hammond has been elected, and has undertaken to fill the onerous office of Honorary Treasurer in succession to Professor Ayrton.

VISITS TO ITALY AND AMERICA.

The Council has had under consideration the continuation of those useful visits to foreign works which were inaugurated a few years ago, and which have proved to be so successful and such a source, not only of pleasure, but, may I venture to say, of educational value to many of our members. It has had under consideration the arrangement of a visit to Italy in the course of next year, and I am now in a position to announce the preliminary arrangements. It is proposed to travel *viâ* Lucerne and the St. Gothard route, leaving England on Thursday,

April 2, 1903, and arriving at Como on Friday, April 3rd; the party will leave Como for Milan on Monday, April 6th, and will disperse at Milan on Thursday, April 9th, the day before Good Friday, so that the members may, if they wish, spend the Easter holidays in Italy, or in Switzerland, *en route* home. I need not say that this will prove a very interesting visit. Our co-engineers in Northern Italy have availed themselves to the utmost of the great water powers that are stored up in the Alps, and we may anticipate not only a most instructive but, from the picturesque point of view, a most pleasant and interesting journey.

I have further to announce that the Institution has received an invitation from the American Institute of Electrical Engineers to visit the United States, and to hold a joint meeting there or in Canada. I have been asked to read this letter on account of its warmth of tone and the welcome that it offers to the members of this Institution :—

"AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

NEW YORK, *July* 21, 1902.

"INSTITUTION OF ELECTRICAL ENGINEERS,
Victoria Mansions,
28, Victoria Street,
London, S.W.

"GENTLEMEN,—There has been a growing desire among the members of the American Institute of Electrical Engineers that arrangements should be made for an official visit of its sister society, the Institution of Electrical Engineers, to this country in the near future. This desire has been fostered and stimulated by the pleasant recollections of those of our members who attended the joint meeting of the two Societies at Paris in 1900, more especially by those who had the good fortune to participate in the enjoyable programme of entertainments and social courtesies extended to the American Institute of Electrical Engineers by the Institution and its friends in England, prior to the Paris meeting.

"This desire has just found formal expression before our Institute; and I have great pleasure in officially informing you that at the recent Annual Convention held at Great Barrington, Mass, June 18 to 21, 1902, it was decided by unanimous resolution that the American Institute of Electrical Engineers do invite the Institution of Electrical Engineers of Great Britain to take part in a joint meeting in this country. The time and place were left undecided, the details of arrangement being referred to, and placed in the hands of, the Committee on Meetings. There were several reasons why it was deemed inexpedient to fix definitely the date and place in the resolution aforesaid, which reasons I will proceed to explain.

"Suggestions were made and considered at the Convention contemplating a joint meeting, either during the year 1903 or the year 1904. The Committee on Meetings is desirous that the Institution of Electrical Engineers, as the intended guest of the American Institute of Electrical Engineers, should first be consulted and should be allowed

to express its preference in regard to both the time and the place of meeting, before fixing the same, in order to avoid deranging any plans which the Institution might have made definitely or might have in view for the year 1904. For this reason, instead of submitting a definite programme and tendering a definite invitation to the Institution, it is deemed preferable to submit to the Institution the outline of two alternative plans.

"The first plan contemplates a meeting of the American Institute of Electrical Engineers at Montreal in the year 1903. At the recent Annual Convention just referred to, a very cordial invitation was extended to the Institute by the McGill University at Montreal, to hold its Convention of 1903 in the Canadian metropolis. It was recognised and universally admitted that such a convention would be more important and enjoyable if the Institution could also arrange to meet with us on that occasion. In such case there would doubtless be a programme of reception and entertainment in New York, either prior or subsequent to the meeting in Montreal.

"The second plan would be to defer the joint meeting until the year 1904, that being the year during which the Louisiana Purchase Exposition is to be held at St. Louis, Mo. This Exposition promises to be a very important affair, since over thirty million dollars will be expended in carrying out the elaborate and comprehensive plans of the Exposition Committee. It is proposed to hold various Congresses, including an International Electrical Congress, at St. Louis during the Exposition. In view of these facts, the Committee think that many members might prefer to have the official visit of the Institution deferred until the year 1904. In such case, the joint Convention would be held in the eastern section of this country, where the American Institute would be pleased to entertain its foreign guests. Our members could subsequently proceed with them to the Exposition and Congress at St. Louis.

"It is, therefore, my pleasure to submit the Institution of Electrical Engineers, on behalf of the American Institute of Electrical Engineers, a hearty invitation to meet with us during the season of 1903 to 1904, as may seem to the Council of the Institution the more convenient and desirable.

"As already stated, it is the desire and purpose of the Institute to conform to the future plans of the Institution, in order that the largest possible number may participate in the Convention. The Committee on Meetings will begin the work of preparing a programme as soon as we receive from you an intimation of your preference and desires in the matter.

"Trusting that we may unite in perfecting a plan that will redound to the interests of both Societies, I have the honour to remain,

"Yours most respectfully,

(Signed) CHARLES P. STEINMETZ, President."

On account of the Italian visit, the American visit could not be arranged for 1903; hence it is accepted for 1904.

General Announcements.

I have further to announce that a deputation of the Council has recently waited on the President of the Board of Trade in connection with the proposed revision of the Board of Trade Regulations. The matter is not ripe now for definite announcement of resolutions, but it is hoped that full particulars may be furnished to the members at a future date.

The Council has been in correspondence with the Home Office in regard to the Factory Act, and has been assured that a full opportunity will be afforded for the discussion of the new Regulations before they are adopted. The Council further have reason to hope that the Secretary of State may see his way to take such steps as he can under the present Act of Parliament to assist the profession in regard to the employment of young persons in electricity works.

I have also another satisfactory announcement to make, namely, that the President of the Institution of Electrical Engineers has been appointed *ex officio* to serve on the Committee nominated by the Home Office to inquire into questions relating to the use of electricity in mines.

On the subject of professional etiquette the Council has issued a code for the convenience of members, and has published it in the technical press. I presume that all the members have made themselves acquainted with the details, and that it is unnecessary for me to dwell further on the subject.

Subscriptions and *Science Abstracts.*

Now I approach what may be possibly considered a very burning question, that relating to subscription rates and the issue of *Science Abstracts.* On June 9th, when the circular in relation to the proposed alteration of the rates of subscription was issued, the Council felt that it was imperatively necessary to increase the amount of the funds at its disposal. The question, I need not tell you, has received very earnest consideration, and the letter referred to was issued in order to elicit the opinion of the members generally. A considerable number of the members have replied, and have expressed their views. I think I may say that, generally speaking, they are prepared to support the Council in the measures that it considers necessary to adopt for the benefit of the Institution. As the result of the fullest consideration, not only of the question itself but of the views expressed by the members, the Council is now prepared to recommend rates which I propose to read to you. It considers that at the present time the rates must be levelled up to the ordinary maximum of each class. Further, it has considered that it is reasonable and desirable to differentiate between members resident abroad and those at home, who get all the privileges of membership and who are able to attend the meetings in London or the sectional meetings that have been established in the Provinces. The recommendations, therefore, are that the whole of the Members in this country shall pay a uniform rate of three guineas, which is the ordinary rate at which new Members enter, and that Members residing abroad

shall pay two guineas; Associate Members at home shall pay two guineas, and abroad one and a half guineas; Associates at home two guineas, and abroad one and a half guineas.

Now I come to another question dealing with the students. Under the present regulations, a student after remaining in the class of students for three years is compelled to become either an Associate or an Associate Member, or to leave the Institution; but it is proposed now to divide the students into two classes, namely, students junior and students senior. For the first three years of a student's connection with the Institution he will pay a guinea annually, or if he be then under 22 years of age, until he attains that age; but he may then, if he wish, and if under 26 years of age, remain until he is 26 as a senior student at the annual payment of one and a half guineas. A meeting of the full members of the Institution will shortly be called, and these proposals will be laid before them for consideration.

I now come to the question of *Science Abstracts*. This question has engaged the attention of the Council very seriously for a long time. *Science Abstracts*, I need not say, is a most valuable publication to all interested in the progress of our science. But the cost of its production has increased and is increasing, and from time to time the question of what amount the Council could afford to pay as its share of this cost has had to be debated. Now it has been felt that the free and gratuitous distribution of *Science Abstracts* to all and sundry of the members, whether they value the publication or not, was perhaps a mistake. Instead, therefore, of adhering to the practice of the free issue of *Science Abstracts* to all classes of members, the Council concluded that if the rates that I have announced were combined with a moderate subscription from those who required the issue of *Science Abstracts*, the equity of the case would be best met as applied to the whole of the members generally. The proposal, therefore, is that those members who wish to be furnished with copies of *Science Abstracts* shall have their wishes met on the payment of an annual subscription for both parts, that is, physical and engineering, of 7s. 6d. per annum, or the engineering portion alone for 5s. I think that deals broadly with the general question of funds. I may say in relation to these proposals that the ordinary publication price of *Science Abstracts* is 24s. per annum.

Approaching Award of Willans Premium.

I am further asked to announce in reference to the Willans Premium to be awarded by this Institution in December, 1903, the Council will, under the Trust by which it is bound, award the Willans Premium "to the best original paper contributed to the Institution dealing with such a general subject as the utilisation or transformation of energy treated specially from the point of view of efficiency and economy, and that the premium shall not be awarded unless a paper of sufficient merit, in the judgment of the Awarding Council, shall have been so communicated since the preceding award of that Council."

The premiums reported in the Annual Report presented in May, 1902, were then presented.

The Three Hundred and Eighty-second Ordinary General Meeting[1] of the Institution was held at the Institution of Civil Engineers, Great George Street, Westminster, on Thursday evening, December 4th, 1902—Mr. J. SWINBURNE, President, in the Chair.

The minutes of the Ordinary General Meeting held on November 22, 1902, were read and confirmed.

The names of the candidates for election into the Institution were announced, and it was ordered that these names should be suspended in the Library.

The following transfers were announced as having been approved by the Council:—

From the class of Associates to that of Members—

Reginald Robert Todd.

From the class of Associates to that of Associate Members—

Gerald Carlyle Allingham.	John Henderson.
H. Borns.	Alfred Edward Jackson.
Frank Cobden Briggs.	Louis Campbell Login.
Denis Ripley Broadbent.	Owen David Lucas.
Frederick W. Close.	Rowland Marshall.
Percy Rhodes Cobb.	Francis Miller.
Walter Eynon.	Walter Victor Morten.
Robert Loraine Gamlen.	Arthur Holroyd Sears.
Harry Philip Gaze.	Charles Arthur Slater.
Harry Percy Girling.	David Smith.
Alexander Glegg.	David Brown Walker.
Selwyn Seafield Grant.	Charles Aspull Wells.
Reginald Charles Harpur.	C. Barnard Wigg.

Reginald Page Wilson.

From the class of Students to that of Associates—

William Hunton.

Messrs. H. G. Wood and P. G. Timms were appointed scrutineers of the ballot for the election of new members.

A donation to the *Library* was announced as having been received since the last meeting from Dr. H. Borns, to whom the thanks of the meeting were duly accorded.

[1] This was an Extra Meeting called to enable members to hear the President's Address, postponed from the Meeting of November 13th. It is therefore printed out of order, and before the Proceedings of November 27th.

The PRESIDENT : Before delivering my formal address I would like first of all to thank the Council, and what is the same thing, to thank the Institution, for the kind way they treated me a fortnight ago when I was unable to read my address.

I also desire to refer to the work of my predecessor, Mr. Langdon. We are all very sorry that Mr. Langdon is not here to-night. I do not think it could do any harm for this Institution to realise if possible a little more the work that Mr. Langdon did for us. Mr. Langdon was handicapped very severely, to begin with, by living up in the Midlands. In spite of that he attended—I forget how many—but something like 82 or 92 Council and Committee Meetings. If any one of you who is living a busy professional life in London realises what it would be to attend 80 or 90 meetings in Birmingham, he will understand the sort of self-denying work that Mr. Langdon did for this Institution. In addition to that, Mr. Langdon's health was not very good, and I think he sacrificed himself on behalf of the Institution several times. Also I wish to refer to a rather marked change of policy in the Institution during Mr. Langdon's Presidency. We owe in a great respect to Mr. Langdon the change in the attitude of the Institution towards making it more commercial, and keeping it more in touch with the purely technical part of our large interests. Mr. Langdon took a very keen interest in all the work of the Institution, and I may mention particularly the questions which ended in a deputation to the President of the Board of Trade. You remember that I was spokesman on that occasion, but as a matter of fact I had only just come into office, and the whole of the work was really done by Mr. Langdon—at least the whole of the Presidential work—and we owe a great deal to him for any good that may have come indirectly—and I believe a great deal of good has come—from the action of the Institution in that matter.

SOME LIMITS IN HEAVY ELECTRICAL ENGINEERING.

INAUGURAL ADDRESS BY THE PRESIDENT,

JAMES SWINBURNE.

Argument.

Two kinds of limit.—Electrical means scientific engineering.—Engineering is Science.—Unapplied and applied science complementary.—Engineering includes both raw and finished science.—Raw science important.—Unfortunate attitude of raw towards finished science.—Development of tidal power not practical.—Fictitious value attributed to water-powers.—Electrical energy direct from coal a dream.—Limits of efficiency of steam engine.—Steam and SO_2.—(Notes. Units. Entropy.)—Limits of gas engine.—Large margin for improvement.—Dynamos and transformers near limit.—Secondary battery progress limited chemically.—Little chance of great improvement.—Cables made empirically; room for advance in insulation, but not in con-

ductor.—Condensers not wanted.—Electro-magnetic condenser.—Enormous unavoidable waste of light.—Arc capable of improvement.—Not studied from all standpoints.—(Note. Back Electromotive force of arc.)—More refractory conductors for incandescent lamps.—Carbides.—Metals.—Electrolytic lamp.—Possibility of direct radiation.—Cooper-Hewitt lamp.—Electric heating.—Want of variable speed-gear for electromotives.—Application of electrolysis limited by ignorance of those interested.

It is customary for a Presidential Address to be a review of the development of the science with which the Institution is particularly concerned. Such a review is especially beneficial in the case of such a rapidly growing industry as Electrical Engineering, as the outlook changes considerably during a year. But other forms are open; for instance I might have devoted our time to the discussion of the work of this Institution, and gone fully into its growth and its doings, and we might have considered what the Institution has done for the Industry, and what it ought to do in the future.

Instead of a review of the past, a dream of the future may take the form of a presidential address. This form has great attractions for me for several reasons. In the first place this kind of prophecy is easy and pleasant. I might draw a rosy picture of a future when everything conceivable is done electrically. We will have electrical energy developed direct from carbon at the coal-pits. Not only all our lighting but all our domestic heating will be done electrically. There will be no smoke in our cities, or in what will correspond to them. Most of the dirt of our houses will have vanished. Large and crowded towns will have disappeared, because the telegraph will have given way to its wireless rival, and that will have given way to the wireless telephone with no exchanges and no subscriptions. There will thus be no need for people to go and see one another to transact business. Even when matters must be written to preserve a record no office will be necessary. You will dictate by wireless telephony to your shorthand clerk at his distant house. Perhaps we will all learn shorthand instead of our present cumbersome system of writing, and all books and letters will be in one language written and printed phonetically at speaking speed, or faster. The horse will have gone, leaving clean and odourless streets, with smooth surfaces on which people travel in rapid electric automobiles. The railways with very rapid long-distance service will be entirely electric. It is very easy to prophesy in this sort of way, not only in a general way but in considerable detail; and it is an amusement that brings much credit to the prophet. If any of his prophecies seem unlikely to come true he merely has to say, "Wait a little!" While if anything like what he foretells comes into existence, say twenty years hence, all he has to do is to refer back to an address to claim that he has foretold it, and the future inventor will have half his credit taken from him and given to the prophet. If the prophecies are sufficiently vague, there is certain to be some sort of fulfilment of some of them sooner or later, and it is always well to have a good many past publications of this sort in stock waiting for future development.

Great though the temptation is, I will resist it, and try to look into the future from quite a different point of view. We have been going ahead so very fast lately,—even our acceleration itself increasing,—that we may be a little apt to have vague views of what we can and what we cannot do electrically. It may be well, therefore, to try and look over some of the branches of our great and diverse industry, and see what obstacles are now opposing us, and what are likely to oppose us shortly, and whether the obstacles are insuperable or not. This sort of prophecy is much more difficult than the other, for there can be no credi twenty years hence in having said something could not be done, even if it has not, while if it has been accomplished the position is still more difficult. Negative prophecy is thus unattractive. But the discussion of our limits may not only have a beneficial effect in making us modest, but it may be a much greater benefit if by focussing our attention on a limit of any development we find either that the obstacle is theoretically insurmountable, in which case we must go round it, or that it has to be scaled in a particular way.

There are clearly at least two kinds of obstacles. For instance, it is obviously impossible to get more than 746 watts out of a dynamo taking one horse-power to drive it. But the limit of possible speed on an electric railway belongs to quite a different category. I will therefore discuss various branches of electrical technology, to see what may prevent or is preventing further advance.

An address is usually taken without discussion. When it deals with views or facts which are generally accepted no difficulty arises, but in this address I must touch on many points which may be controversial. It must be remembered, therefore, that though I do not insert "I am of opinion" or "I think" before every proposition, that is all any statement, however definitely made, amounts to ; and I will ask that what is for shortness stated dogmatically should only be taken as personal opinion, and be accepted or rejected on the grounds given or understood, and not in any way on authority.

Twenty years ago this Institution was chiefly concerned with the development of the telegraph. We can get but few telegraph papers now. This is not because Telegraphy is dead ; it is because most of its problems are solved, so there is little to discuss. The fact that there is little to discuss in telegraphy is the proof of its vitality. It has passed out of the childhood of technical difficulties into the manhood of commercial development. Ten years ago we were in the thick of the evolution of the dynamo and the transformer. Now there is little but detail to discuss about electrical generating machinery. This is because heavy electrical machinery has got through its difficult infancy, and is now a trade, which is the highest compliment that can be paid to it. But we electrical engineers have also developed through our difficult training into being the scientific branch of the engineering profession. Our exactness of calculation and measurement has leavened the steam engineers, and the other manufacturers with whom we have to work in concert. But this must enlarge our mental view and move out our horizon. We must not say that because we can buy efficient dynamos and order accurate instruments that we need have no technical know-

ledge. Quite otherwise, we must understand dynamos as before, also measuring instruments, but we must also understand steam engines, gas engines, fuel questions, financial matters, parliamentary matters, tramway matters, railway engineering, and very soon railway management. All these are the work of the electrical engineer. No one man can be a complete electrical engineer; but each of us ought to know one subject well and a large number of allied subjects fairly well.

As a basis of technical knowledge, which I am alone dealing with to-night, we must have a fairly all-round knowledge of "theoretical" physics and chemistry. Physics is merely unapplied engineering. Science is split—unfortunately the split is very difficult to heal—into two parts, generally wrongly called the theory and the practice; or pure and applied science. This fissure is not so deep in our branch of engineering, but it is there. Science, to be worthy of the name, is knowledge of Nature utilised by man. Engineering is science, and science is engineering. You can cut off a part and call it Unapplied Science. This is what is generally known as Theory or Pure Science. It is not purer than any other science, and the term Theory is misapplied. To be an engineer you must know both branches. There is nothing superior about knowledge which is not yet applied. It is mere raw material; it may be useful when worked up, and it is valuable before it is worked up, but only because it may be worked up. The so-called practical man who works at applications without understanding the generalised principles is ignorant. He only understands a part of science. The so-called scientific man who only understands what is called pure science is just as ignorant. Each understands part of his subject only. Specialisation demands sacrifice of general knowledge to gain particular, but the "theorist" and the "practical man" are both ignorant of half science. Very sinister is the influence of the "practical man" who despises "theory" and thinks everything abstract, or mathematical, or chemical is better left unlearnt, and who glories in his so-called "practical knowledge"; but just as sinister is the attitude of the half-scientific "theorist" who thinks his own kind of knowledge includes of necessity that of the "practical man." The, may I say, somewhat supercilious attitude of the (from this point of view) half-educated scientific man, who only deals with the raw material of knowledge, has done more to increase the gap between applied and unapplied science than any action of uneducated manufacturers. The sort of tacit assumption that an engineer can never be a "scientific man," while a "scientific man" can teach the engineer his business, cannot fail to annoy the engineer, and this feeling of annoyance is largely the cause of a great deal of opposition to technical, that is to say, really scientific education.

Perhaps the votary of unapplied science sometimes feels that it is hard that people who only possess, in his opinion, a kind of knowledge which is unworthy of the name of Science should be able to secure more fishes and more loaves. He must remember that he gets more kudos. Moreover, unapplied science is pleasanter to acquire. Most of us would rather read chemistry or mathematical physics or study, say, the eccentric little ways of radio-active bodies than design coal con-

veyors or tabulate meter charges. But the great work of the world and the making of character depend on people doing what they dislike, not what they like. The world will requite with cereal and marine produce the man who does what the world wants. If he has to spend his earlier years over the applied half of science, and has little time to indulge in the pleasures of the other half, because as a young man he only gets very little black bread and the meagrest kind of kippered fish, he is enabled to give the world more useful work later in life, and eventually earns more amylaceous and brain-forming material; and the man who has preferred to indulge in the more interesting but less useful half of science should respect his knowledge, and should not cast envious eyes on the enormous income of starchy and phosphoric material the practician has to pretend he makes. The raw science man has his own reward. He has pleasanter work, that most would like, and he has in proportion a much better position. Each branch has its own peculiar advantages, and there ought to be no sort of antagonism. I would plead for more mutual respect, and a better understanding among scientific men, and closer fellowship among those who study raw science, and those who deal with it in its finished form.

We as electrical engineers ought especially to heal the split between the two halves of science; a split which is much deeper in other branches of engineering, such as chemical and purely mechanical. We ought to unite knowledge of both branches of science in one individual as much as possible. The electrical engineer must not be only an overgrown wireman, a mechanical engineer with a little electrical knowledge, a mathematician, a financier, a lacquered brass and sealing-wax varnish instrument maker, a physicist, or a manager of men. He must be all of these, in different proportions in different people. Our Institution should equally deal with all parts of our knowledge. We ought to have papers on the value and cost of fuel and on electrons; on the best way of arranging piece-work, and on the thermo-dynamics of the dissociation theory: on the "skin" effect and cylinder-condensation; on the relation of *e* to borrowing powers; on Wien's law and the proper charge for lamps on variable circuits; on the relation of the refractive index and specific inductive capacity and the electro-magnetic theory of light, with special reference to the waste of power in alternating rubber cables; on thermo-dynamic potential applied to making manure by fixing nitrogen; Guldberg and Waage's law and gas engine combustion; on tube railways, Hertz waves, wireless telegraphy, strikes, blast furnace gas, submarine telephony, automobiles, standard cells, tramway cars, and everything that concerns electrical engineers. This session the Council hopes to deal with a varied assortment of such questions, holding as even a hand as possible between the various branches of our subject. No excuse is therefore needed for ranging over a fairly large area in an address. To keep within reasonable limits of space our attention will be confined to heavy electrical engineering, thus omitting the electrical transmission of messages. Even then each subject can only be treated very shortly indeed.

Tides.

The tides are often referred to as a possible source of energy even to this day; and it is urged that in places where the tide rises abnormally, for instance in the estuary of the Severn, it would pay to make a dam with turbines. The sort of argument is that if you have an area of, say, 1,000 square metres, and a total rise of 15 metres, you have 15,000 cubic metres of water, and as this runs in twice and out twice a day, you have 15,000 cubic metres of water, falling the equivalent of 60 metres a day; or approximately 100 kilowatts. This statement contains many fallacies. In the first place, in order to get the full advantage of the difference of level the water must be let in and out at high and low tide only. Even then the equivalent, or average head during discharge or charge, is only 7½ metres. But a system which gave an enormous power for a very short time four times a day would be of no use. The plant would be expensive, and the result of no value. With a single tank it is impossible to get a continuous output. If the tide is coming in, and you get power by letting the tide fill the tank, the power will decrease to zero as the tide begins to fall and comes to the same level as the water in the tank. It is, therefore, necessary to have more than one tank. To make the plant practical you want fairly constant pressure available on the turbines, though you may waste head by sluices or valves. Then the tank may be divided up into three, one of 200, and two of 400 square metres. The small one is emptied at each low tide and filled at each high tide. Starting at half tide, with the tide rising, and the 200 and one 400 metre vat empty, and the other 400 quite full, the small tank takes in water at such a rate that at high tide it is half full. It thus takes in 1,500 cubic metres of water with a useful head of 7½ metres for three hours. This gives 10 kilowatts. At full tide the large empty tank is allowed to fill through a turbine working on 3¾ metres, but taking twice as much water per minute, and this goes on till half ebb tide. The small tank is rapidly filled to high tide level. At half tide the large tank has 3¾ metres of water, and the head is getting too small, so the small tank is now allowed to empty for three hours with 7½ metres fall, until low tide. From low tide to half tide the second large tank is emptying from the 15 to the 11¼ metre level. By means of these tanks, of total area of 1,000 metres, and two turbines and one dynamo we thus get 10 kilowatts going into the turbines. If the tide—and the neap tide must be taken—is only, say, 4 metres, we only get 700 watts! No doubt the tanks and turbines might be worked somewhat more profitably than I have sketched, but there can be little margin. Turbines to work on variable pressures, or any sort of storage, mean more capital expenditure, and it is the great capital expenditure that wrecks tide schemes. It is often said that a Norwegian fiord or a Scotch loch could be easily dammed and utilised; but it would be impossible to find three lochs all opening out together. The need for more than one reservoir does not seem to have been recognised. In addition the demand for electrical energy on Scotch lochs or Norwegian fiords is rather minute.

Water Power.

Some years ago there was a great deal of excitement about the development of water powers. The possibility of "harnessing Niagara" and utilising water-falls all over the world was hailed as a great triumph over Nature, and the idea was that power could be got for nothing, and industries would all migrate from coal districts to the neighbourhood of water powers. The daily press and the magazines took the matter up, and there is something in the idea of saving some of the colossal waste of natural energy that appealed especially to the half-scientific or unpractical reader. At the time of the excitement it was pointed out, largely in vain, that water power did not cost nothing, because the development of a fall demanded a good deal of capital, whose interest and depreciation had to be paid. But further than this, Ricardo's theory of rent is applicable to water powers as well as to arable land. If steam power costs a farthing a unit, and if water power at the same place can be produced for half a farthing, after paying working expenses and interest, the owner of the water power will claim the odd half farthing as rent, or will just allow the water power enough to encourage the production of a new thing. As a rule, however, a water power is not where it is wanted industrially. In the nature of things water powers are generally in hilly countries, and are seldom near the sea. The result is that a water-power as a rule cannot command the same price as steam or gas, because it is not where it is wanted. The idea in starting many of the water-power stations also was that works which needed power would come and settle near. As a matter of fact the cost of power is a much smaller item in most industries than is generally supposed, and it does not pay to start a works in an otherwise not perfectly suitable locality, simply for the sake of the cheap water power. In such industries as engine building, flour milling, spinning and weaving, and so on, the chance of reducing the expense for power is not enough to overcome other considerations. It may said that in electro-metallurgical processes the whole cost is practically the electrical energy, and so carbides, aluminium, and electrolytic soda, and chlorate of potash will be made at water powers. Even this, however, is misleading. Carbides and aluminium are generally made at water-falls, and chlorate nearly always is. Electrolytic soda and bleach are made at water powers, but are also made extensively by steam-driven plant. Against the cheaper power, we have to put extra carriage for materials and for coal, which is often needed in addition, and extra carriage for finished products, and very often extra cost of labour, as labour is often dear and bad in water-power districts. Let us take, as an example, calcium carbide. The general idea is that the electrical energy is practically the whole cost of the carbide. Taking present practice, however, a kilowatt makes about two tonnes, or say two tons of carbide a year. The difference between water at, say, £2 10s. and £5 a kilowatt year is thus £1 5s. a ton in cost. The price of carbide may be taken at £13 10s. a ton, so doubling the cost of power instead of nearly doubling the price of the carbide would increase it a little more than 10 per cent. Difference in local cost of

coke, lime, and labour, coupled with cost of carriage, may thus easily be of more importance than cheap power even in such a case as calcium carbide, which is an electrical furnace product in which, at first sight, the power seems to be the main element of cost. In the case of electrolytic caustic and bleach, for one ton of caustic and the corresponding bleaching powder, the electrical energy, taken at £2 10s. per kilowatt year, a low water-power cost, comes to about 17s. 6d. The caustic and bleach sell for about £20, according to a varying market. Doubling the price of power therefore increases the price some 5 per cent. It may thus easily pay to use much more expensive power, if the other conditions are more favourable. Steam power, for instance, will cost 3 or 3½ times as much, and yet it pays to make electrolytic caustic and bleach in England where the other conditions are all favourable. It is not, therefore, the want of water power that has kept the electrolytic industry back in this country. For a water power to be really valuable, it should be near a source of material, on the sea, and should have a great head of water, so that the capital cost of development is small. Such a water power is very valuable—to the landlord.

A blast furnace is more valuable than a water power. There are plenty in England. But the owners, who have been wasting the gas up to now will not give it away; they will want rent, so that it will only just pay to use his gas rather than make it. The electrical industry thus does not gain, but the iron-masters do.

Carbon Cells.

For many years "electrical energy direct from coal" has been the dream of the electro-chemist. That is to say, he has dreamed of an electrolytic cell in which the consumed electrode is carbon. The best way to realise the difficulties of this problem is to consider it solved and see what it means. The carbon must be in contact with an electrolyte, and that electrolyte must either be in contact with a second electrolyte which wets the other electrode, or must itself be in contact with that electrode. This second electrode must almost certainly be metal, as there are no other non-metallic conductors available. The electrolyte in contact with the carbon must be a salt of carbon, or must contain a salt of carbon, or it must contain another salt whose positive radicle can be replaced by carbon. Such compounds as the hydrides, nitride, oxides, chloride, bromide, or the sulphide, or silicide, of carbon are not salts in the electrolytic sense. Carbon forms part of the electro-positive radicle in the organic radicles, and part of the electro-negative radicle in the cyanogen compounds, but it is never a radicle by itself. To sum up the matter shortly in the light of modern theory, carbon never forms ions, and has therefore no solution pressure, and can therefore give no electromotive force.[1] At ordinary or moderate temperatures carbon is practically inert. Oxidising agents will attack some forms slightly; and sulphuric acid will attack it. In this latter case the formation of water and its combination with the acid

[1] See however, Billitzer, Monatsh. 1902, 23, 502.

is the determining factor. At high temperatures, oxygen, sulphur, silicon, and to some extent nitrogen, and many of the metals, combine with carbon, but there is no dissociable salt of carbon formed. The carbon cell thus seems impossible. Such schemes as Mr. Reed's, ingenious as it is, is not a solution of the problem. It would be simpler to reduce zinc oxide with the carbon, and then put it in a zinc cell.[1]

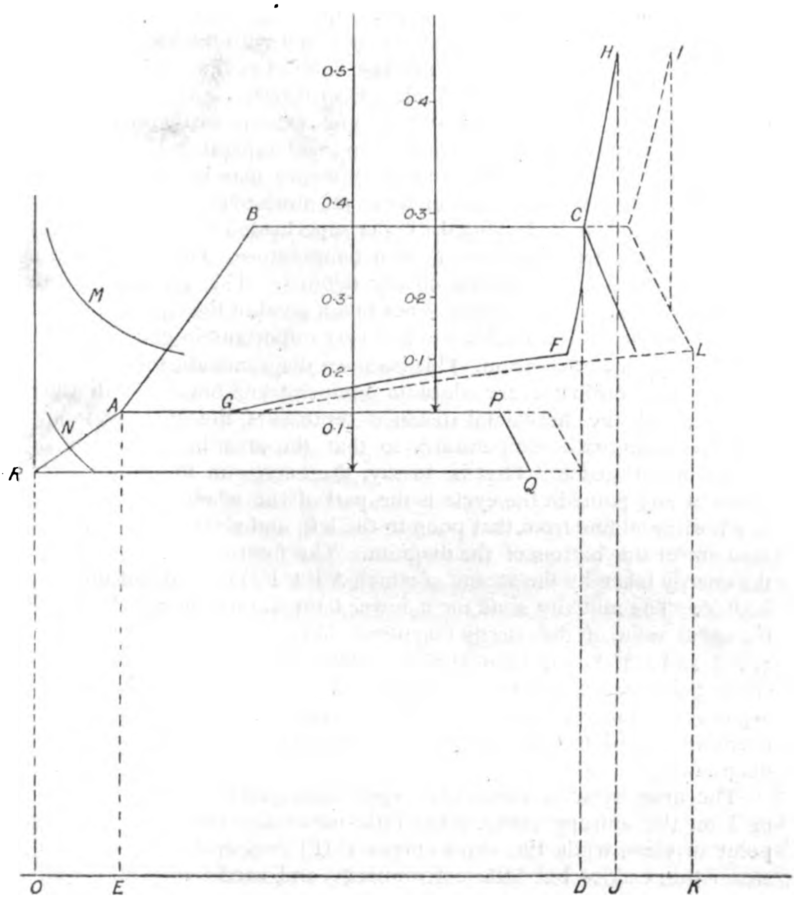


FIG. 1.—θ,χ and θ,ϕ curves for Steam and Sulphur Dioxide Engine.

It is hardly necessary to discuss thermopiles or thermo-magnetic engines as possible economical producers of electric power.

Steam Engines.

The primary question in all heat motors is: What temperature

[1] For a full discussion of the carbon cell see *Primary Batteries*, by W. R. Cooper. E. de Fodor, in *Elektricität direkt aus Kohle*, Hartleben, Leipzig, also gives a full account of work done on this problem up to 1897, the date of the book.

range is available? In the case of a steam engine there is enormous waste of mutivity[1]—to use a variation of Lord Kelvin's convenient term—in boiler flues. We burn carbon and hydrogen, capable even with air of giving a temperature of some 1,500° C., and the heat is degraded down to some 200° C. That is to say, instead of getting the heat with a mutivity of about 0·825, we degrade it down to, say, 0·35, a clear loss of 0·45 out of 0·8, or 56 per cent. This degradation is apart from the efficiency; the efficiency is concerned with the loss of heat up the chimney. The higher limit in large modern reciprocating engines may be taken roughly at 600° A. (327° C. or 620° F.). Above this there is difficulty in lubrication, and to some extent weakening of the material. The pressure corresponding to this temperature for saturated steam is out of the question, and the pressure may be taken at, say, 12·5 megadynes per square centimetre or 12½ atmospheres,[2] or 200 lbs. per square inch, and steam leaving the boiler superheated to 600° A. does not get at the cylinder lubrication at that temperature. Our limits in the steam engine are thus pretty clearly defined. The pressure is the essential factor. Superheating is not much good in the way of getting higher mutivity in the boiler, nor is it very important in getting much more energy into the steam. This is shown diagrammatically in Fig. 1. The vertical ordinates are absolute temperature, but in Centigrade degrees, and the horizontal distance represents the quantity factor corresponding with temperature, so that the area is the energy of a gramme of steam. That is to say, the energy in the gramme of steam at any point in the cycle is the part of the whole area included in a horizontal line from that point to the left, and a vertical line to the zero line at the bottom of the diagram. The figure A B C D E is thus the energy taken by the steam, of which A B C F G is used and the rest wasted. The mutivity scale for a lower temperature of 338° A. shows the small value of the energy taken in. This curve is for temperature 473° A. and 338° A., 200° C. and 68° C., and the exhaust is opened at 382° A. causing the wedge-shaped loss on the lower right-hand corner. The expansion is taken as adiabatic without cylinder cooling. To the right is shown dotted to the same scale the ordinary temperature entropy diagram.[3]

The mutivity scale shows that superheating up to H on the energy or I on the entropy curve, gives little advantage from the mutivity point of view, while the extra energy C H J D is small. Superheated steam thus carries but little extra energy, and carries that little without much extra mutivity. But superheating steam is very important for ordinary engines as it reduces the expansion condensation, and what is much more important, the cylinder condensation. It has been proposed to reduce cylinder condensation by coating the piston and cylinder cover. Perhaps enamelling them would help. The walls even in a short fat cylinder give most trouble. Hadfield has proposed alloying the surface. The alloy would have to be mechanically suitable and ought to have low specific heat and low conductivity.

[1] See Note A, p. 36. "Mutivity."
[2] See Note B, p. 37, "Common Sense and Scientific Units."
[3] See Note C, p. 37, "Entropy."

Jacketing is also used to reduce condensation. As long as the cylinder is hotter than the steam there can be little communication of heat; the trouble is, that if the surface is wet evaporation cools the metal. The jacket should therefore keep up such a flow of heat through the cylinder walls that there is no deposit from expansion condensation, so that the walls never get wet. Pouring heat through a cylinder wall into colder steam is itself an uneconomical process, meaning increase of entropy. Superheating proves to be the easiest and most economical way of dealing with a source of waste that is inherent in a reciprocating engine. But the weight of steam should not alone be used in comparing the performance of an engine with superheated steam with another. Throughout the pressures in common use a kilogram of saturated steam takes sensibly the same heat to evaporate it, and there is such a great fall of mutivity in the flues that a boiler can evaporate at one temperature nearly as economically as at another, so the weight of steam used is a measure of the badness of the engine. But superheated steam takes more heat to produce it, so that a boiler with a given coal consumption and chimney temperature gives less.

Our upper limit in the engine is thus somewhere about 473° A. for saturated steam with a mutivity of, say, 0·285, with a little addition up to 600° A., with an average mutivity of, say, 0·37. An extra temperature or "superheat," as it is somewhat barbarously called, of 127° thus would give very little advantage if it were not for the inherent badness of the engine. I am here dealing with large high-class engines. Superheating is of very much greater advantage with the ordinary small and middle-sized engine in common use. The lower limit is, however, of great importance. If we could work down to the temperature of the air we would gain greatly. We cannot do so because the engine would have to be enormous. The θ, v curve is shown at M to a small scale. It shows the volume becoming unmanageable. A great deal of condenser water would also be needed. A two-fluid engine is theoretically possible. We want a second fluid which gives a higher pressure at, say, the temperature of a condenser, or better at the temperature at which it is inconvenient to expand steam any further. I have taken sulphur dioxide as an example, because most of the data are available, and because it is being tried in Germany, though I have not seen any accounts of results. If a higher temperature than the one I have taken were used, the lower right-hand corner of the steam diagram would be saved. The lower closed area A P Q R is the energy curve of the corresponding weight of SO_2. I have only considered the internal energy, or U, of the fluids for simplicity. It is accurate enough for the purpose of explanation. The curves are not minutely accurate either. The additional area A P Q R is thus, theoretically, clear saving due to the use of SO_2, which enables a second engine of reasonable size, as it were, to continue the useful expansion down to a temperature little above that of the air. The θ, v curve N, which takes the place of the continuation of M, shows graphically the convenience of going to a second working fluid. How far such saving will pay will be proved to us in Germany. There appears to be room for economy.

The turbine is under the same limit as regards pressure, in fact high pressures are perhaps even more difficult to use, and superheating does not, as already explained, seriously increase the mutivity of the heat taken in by the boiler. The turbine is almost perfect thermodynamically. There is practically no variation of temperature of any part of it, so there is no growth of entropy by conduction. Wire-drawing produces kinetic energy which is wholly convertible into work. There must be increase of entropy, however, through eddies and steam friction. In fact, one aim in design is to avoid the turbine being a large "porous plug." There is no admission condensation, and the increase of entropy of the steam passing through should prevent any expansion condensation. If superheating is necessary to prevent expansion condensation, it is the highest compliment to the designer, for it shows the wire drawing due to irreversible expansion and that due to the leakage, and the axial conduction of heat taken together are not enough to prevent expansion condensation, and the accompanying friction and entropy production near the exhaust end. Comparatively little superheating decreases not only the water, but the heat consumption of a Parsons turbine.

One of the chief disadvantages of steam engines for stations with small load-factors, is the difficulty of storing energy so as to get uniform boiler load. Batteries are no longer used for this, and the difficulty reduces the value of steam in comparison with the gas engine. Mr. Druitt Halpin has proposed, and used "Thermal Storage." Lagged vessels are filled with water raised to the temperature of the working steam. This arrangement, however, is not isothermic; that is to say, to get out the energy the temperature must fall. What is wanted is a reservoir containing something which undergoes a physical or chemical isothermal change. For instance, a substance that fuses at the right temperature, and has a high latent heat of fusion, or a substance which like sulphur changes allotropically with considerable change of internal energy, at a suitable temperature. Unfortunately, there is no substance within the range of practical enigneering. Moreover, the storage is on the wrong side of the engine. To store heat with a mutivity of only some 0·35 is not so promising as to store some higher form of energy. The secondary battery thus begins with an apparent advantage. The difficulty of storage is another drawback to the steam engine, and gives the gas engine a further advantage.

Before leaving the steam engine it may be in place if I bring before the Institution a recommendation of the Institution of Civil Engineers that in future the British Thermal Unit be written B.Th.U. instead of B.T.U., as B.T.U. is used for "Board of Trade Unit."

The Gas Engine.

There is no other comprehensive name that covers the type of engine worked by gas and oil. The combustion need not be internal, and perhaps will not be internal in the future, but in a sense all are worked by gases.

The simplest ideal form is a machine that pumps a small volume of air under a high pressure into a furnace, and draws out a large volume of gases at the same pressure and a very high temperature. The engine should then expand this gas down to the temperature of the air. The limits of the gas engine are essentially constructive, and the difficulties in the way of large gas engines are enormous. Theoretically the gas engine has a very great advantage. The possible range of temperature is so high that the mutivity approaches unity. In addition to this the combustion, whether inside the engine or not, is very efficient. But a reciprocating engine cannot work at the temperature of burning carbon, or hydro-carbons, so that furnace gas at, say, 2,000° A. cannot be led along pipes and used in a reciprocating engine. If the mutivity is sacrificed and the furnace gases diluted with cold air from the pump this plan is inferior. The high temperature can be used by burning inside a cylinder or explosion chamber cooled by water. The hot gas is then surrounded by a cool layer, but most of it is at a very high temperature. Then we come on two difficulties. First, if the gases are exploded there is great strain on all the working parts. Next there is difficulty about the expansion. It would be good to make the engine compound, but then the valves give trouble. The valve has to deal with a rush of gas, which in a compound engine would be little below the explosion temperature. Even with great expansion in a single cylinder there is much difficulty about the exhaust valve. Piston valves are alone used for steam at high temperatures, but for much higher temperatures such as the exhaust of a gas engine, a mushroom valve is generally employed. Opening a mushroom valve against the gas in a large engine means a matter of tons. There would clearly be difficulty in leading hot gases about through complicated valve passages to intermediate and low-pressure cylinders. All the same, when gas engines have the field to themselves and compete closely, the compound gas engine must come in. At present we waste a great deal of energy in the exhaust, and we have to make the cylinder large enough for the expansion, and strong enough for the explosion. Then as the exhaust is chemically different from the original mixture we must either halve the power by using the Otto or Rochas cycle, or we must adopt some other method of scavenging, or use an auxiliary compression pump. It is thus clear that though we begin with gas at going on for 2,000° A., with a mutivity at a lower temperature of the air 0·86, we have to exhaust at such a high temperature that the mutivity is, say, 0·4, or a little better than in the steam engine. If a certain range of temperature is available, it is better to have it at a low temperature, so that the mutivity is greater. Raising both temperatures is like hoisting a reefed sail higher without unreefing it. (Except in a heavy sea) the lower part of the sail is most efficient. We have thus in the gas engine a machine which from a thermo-dynamical point of view ought to be exceedingly good ; but the difficulties in building, especially very large engines to utilise the high possible mutivity, and saving by having the heat produced where used, reduce the efficiency of the gas engine enormously. In spite of that, the large gas engine seems likely to oust the steam engine for large powers during the next

few years. The best way to get a high efficiency out of a gas engine would probably be to make it compound, exhausting at a temperature suitable for raising steam. The steam engine would then exhaust at a temperature suitable for raising SO_2 vapour. But the chances are that Dowson, Mond, or other producer gas will be available at such low prices that the extra steam and dioxide engines would not pay for attendance, interest, and depreciation. With very cheap gas the first thing is to make big engines, the next to make them so that they never break down, and the last thing, to make them efficient. The gas engine may be, comparatively speaking, in the state Watt left the steam engine, but it will doubtless make very rapid advances, as it is in the hands of very competent and highly educated engineers.

I have said nothing about the oil engine, of which the Diesel may be

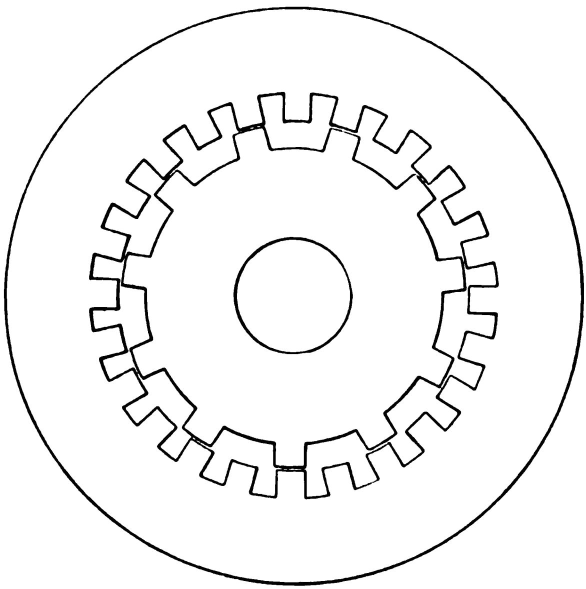


Fig. 2.—Rotary Field Direct-current Dynamo.

taken as the most prominent example. I have never seen or tested a Diesel, but see no reason why it should not be as claimed. There seems to be great prejudice against it, because it is novel. When people, especially English people, strongly condemn a new thing without giving specific reasons, it is safe to conclude that it is very good.

Dynamos.

As regards efficiency we have reached the practical limit already, for further reduction in dynamo losses would make no appreciable

difference in the total efficiency of a station. In fact we are rather following Continental practice in having slow-running machines with many poles, even for direct currents, and efficiencies are perhaps lower for large machines than in the best English practice of a few years ago. This is also true as regards output from a given size. We are not likely to make much advance in dynamos now, as we are limited on one hand by the hysteresis loss in iron, which prevents our using higher inductions in armatures, and low permeability which limits our field and armature tooth inductions. It does not seem likely we will now find iron much better in either respect. Nor are we likely to find a better available conductor than pure copper. As insulator we have mica. It looks, therefore, as if we were within sight of our limits in dynamo and motor designs.

Though dynamos are limited in speed, generally to that of the driving engine, it is possible to make a dynamo give an output corresponding to a much higher speed. In order to get several periods per revolution, alternating dynamos have perhaps from the beginning been made with a number of field and armature coils, so as to be in a sense a collection of elementary dynamos. Mr. Mordey showed how to make an alternator with only one armature and one field-magnet coil. Fig. 2 shows a way of getting a pressure corresponding to a high speed in a direct-current generator. The field has a number of N. and S. poles in succession, as usual in an alternator. The field is laminated. The armature is drum-wound as if for a two-pole field, and it has teeth which come opposite N. poles on one side of the machine, and S. on the other. A very small movement of the armature causes the positions of correspondence to change rapidly, so that the magnetic field rotates rapidly. Thus if there are 11 armature teeth and the speed is, say, 200 revolutions, the field rotates at 2,200, giving the corresponding pressure. If the field rotates with the armature the effective speed is 2,000; if the other way, 2,400. The difficulty in such a machine will arise from magnetic leakage. The armature reaction is also considerable. But reversing devices analogous to those proposed and used by Edison, Houston, Sayers, Atkinson, and others are available, and the machine may be made so that the armature largely excites the field in the case of a generator, and wholly excites it in the case of a motor. It is a question whether such a device as this may give us a light compact railway motor.

Transformers.

In alternating transformers there has been little room for improvements for the last ten years. The "ageing" of the iron was a trouble but now there seems little possible advance.

Secondary Batteries.

The secondary battery in central station work has been used as a store to equalise the load, and to reduce the running plant at the

times of heavy load. Owing to the high full-load station pressure with feeder systems, the station battery is generally for use at light loads only. But the secondary battery has for a long time been on the border of success for traction work, both on tramways and on the road, and a further improvement in batteries may be expected to produce very great changes in important branches of engineering.

The first question asked is, Why do we stick to lead? The answer is that the case is very special and other things will not do. We are practically limited to lead, at any rate in acid cells. Take first the plate that oxidises on discharge. It should not dissolve in the electrolyte, as if it does the deposition and solution will be uneven, and the plate will grow trees and come to grief. This puts zinc out of court. unless some electrolyte is used which gives some insoluble salt of zinc, which does not attack zinc on open circuit, and which gives a good electromotive force with it. Iron is out of court for the same reason: there is no suitable electrolyte. The strong organic acids such as trichloracetic or oxalic are apt to have their positive radicles split up by electrolysis, even if a strongly positive metal can be found with an insoluble salt. Lead is thus the only metal practically available in an acid electrolyte. Silver in hydrochloric acid would give no pressure, and the acid would be decomposed at the anode. On the other plate we need an insoluble depolariser, else a two-fluid cell must be used, involving a porous diaphragm, diffusion, and impracticability. Not only must the depolariser be insoluble, but it must be converted into an insoluble body on discharge. The coating must be a conductor in one state or the other, or there will be no proper contact. In the lead cell there is always enough peroxide and metallic lead in the coatings to secure electrical contact though the discharge product is an insulator. The depolarising coating must be connected to a conducting plate which is not attacked by local action. Lead and silver are the only available metals, and sulphuric, and perhaps phosphoric, the only acids, for the nitrate of lead is soluble and hydrochloric acid is decomposed by lead peroxide. Lead is protected by its coating of sulphate, or peroxide as the case may be.[1] It thus seems as if we were limited almost absolutely to lead and sulphuric acid. It is wonderful that we have the lead cell at all. We owe it to the chance observation of Planté. The theory was not understood for a long time. For many years it was thought that the pressure was due to the PbO_2 and Pb changing into PbO. The acid was merely put in to make the electrolyte conduct, and sulphuric was used because people used it in gas voltameters, and they never thought that it ought to be as strong as practicable to give the pressure and output. The formation of lead sulphate was regarded as a difficulty to be overcome.

In the lead cell we want lightness, large capacity, cheapness, rapid discharge, efficiency, and mechanical strength, and durability. These qualities are mostly antagonistic. Large capacity means rapid deterioration. Mechanical strength means weight. It is thus no use testing a cell for capacity without testing the efficiency and durability too, and

[1] See papers of the late Gladstone and Tribe, and Drake and Gorham.

so on. Published battery reports are often misleading, because they omit essential information.

In an alkaline electrolyte such as caustic, such metals as iron, nickel, cobalt, and copper form oxides which are insoluble. The metals are thus electro-negative in caustic, like gold or platinum in acid. The electrolyte here acts merely as a conductor, as the dilute acid was supposed to act in the lead cell. The pressure is thus chiefly due to the change from metal to oxide on one plate less the reduction on the other, and is small. There may be a Gibbs-Helmholtz temperature coefficient pressure in addition. Though the pressure is smaller, the metals admit of light plates or grids, and the coatings may conduct in both states, instead of only one as in lead cells, so that a larger proportion of the coating may be active. The future of this type of cell is uncertain, as very little has been published as to results. Our limits in secondary batteries thus seem to be settled by the need of having insoluble electrodes and insoluble coatings.

Cables.

The conductor itself can hardly be improved, but there is great room for improvement in the insulation. It is largely the insulation of the cables that limits our pressures, and therefore our distances of transmission. For 1,000 kilowatt cables the cost is about a minimum for 8,000 volts; above that the cost of insulation increases faster than the cost of copper falls. It is exceedingly unlikely we have reached the limit in insulation. There is no branch of electrical engineering so important as cable making. Cables form a large portion of the capital outlay in large systems. Yet there is no branch of the industry which is run on less scientific lines. The days of secret mixtures known only to the workman who makes them may be passing away; but even now the whole art of cable-making is a question of trial and error, with a good deal of the last component. Engineers do not know now whether rubber is better than paper, nor can they tell what any particular make of cable will be like after ten years' use. We do not even know how to test a cable. Sometimes we test it as if it were a telegraph wire; at other times we test with twice the maximum pressure, and if it does not break down, we trust we have not injured its constitution, and put it down. Or we break down a little bit and assume it will all stand some proportion of the break-down pressure.

Apart from resistance to rupture and leakage, capacity and dielectric hysteresis are important factors. In alternating work capacity may produce very unexpected effects. In series with an arc, say at a switch, oscillation may be set up. When condensers were made at Teddington they were sent out with printed instructions to avoid switching off. They had to be switched off in shunt to or in series with a resistance. The loss of power by dielectric hysteresis has again been discussed recently; and whatever its exact amount may be in different cables, it is often a very serious factor. We do not seem to have arrived at anything like the lower limit of this yet.

Overhead bare conductors for very high pressure are not used in

this country. There is a fairly definite limit to the pressure available. When the fall of pressure, or dielectric stress just round the wire exceeds the breaking-down value of air, the air is "torn" and discharges take place which involve considerable loss. This can be reduced by increasing the size of the conductor. It may thus pay to use aluminium or even zinc, or a combination for very high pressure overhead power transmissions. If zinc falls in price much relatively to copper, it may come into use for bare conductors.

Condensers.

It is hardly worth while discussing condensers now, as there is generally excess of capacity on systems, so that the current leads relatively to the pressure; and there seems to be no demand for condensers. Condensers can be made which will hold their charge for several weeks without perceptible fall of pressure. Bringing the poles of a large station within a small fraction of a millimetre over an enormous area with nothing but a few thicknesses of paper between them does not appeal to an engineer. A more mechanical form of condenser might be made, as in Fig. 3, if it is ever wanted. A coil of copper or aluminium is held in a strong radial field so that it is free to move at right angles to the field. If the equation of motion is worked out it will be found to behave like a condenser on an alternating current. I do not know how it would sound. Some ten or twelve years ago I urged the use of over-excited synchronous motors for taking up idle lagging currents. This method is now used frequently, and it lessens any demand there might be for condensers.

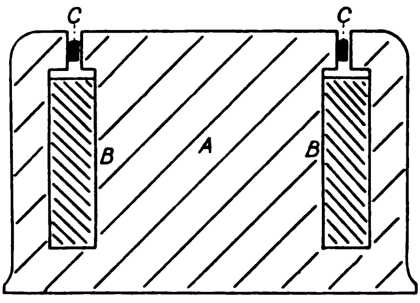


FIG. 3.—Electro-magnetic Alternating Condenser. A, field magnet; B, exciting coil; C, armature coil free to vibrate vertically in a radial field.

Light.

Our chief work, until lately, has been producing light. Here the inefficiency and waste is prodigious, and though it is mostly unavoidable, there is still great room for improvement. We take geat care over our stations, watching every penny from the coal shovel or mechanical stoker to the station meter. We quarrel over 1 per cent. in the generators. When we get to the mains we care less, and once we have got to the consumers' meters we care nothing at all.

Practically all light is wanted for use by the human eye. The human eye is exceedingly sensitive; it is calculated to see a distant

star when receiving 10^{-8} ergs per second, so that one watt would enable, say, five thousand billion people to see stars with both eyes, but it would have to be used economically. In reading a book the eye would need much more than this; and then, as the book radiates light in half of all directions, only a little is used by the eye, so even if all the light from a source were concentrated on a book there is enormous waste by useless radiation from the book. But the source of light does not illuminate only the book; the book probably subtends a small solid angle, so we have another source of waste. The eyes reading a book in a fairly good light want something of the order of two ergs per second, so that a watt would only work the optic nerves of, say, the inhabitants of London. But the book, say 200 square centimetres, would need about 3,000 ergs a second to illuminate it. A candle,[1] which gives a light of 4π, radiates about 0·2 watt or five candles a watt; that is to say at an efficiency of unity, we would get five candle-power or 20 units of light per watt. The efficiency of a glow-lamp is only about 0·25 candle-power per watt,[2] or 0·05, so there is room for improvement. The first thing, naturally, is to see what limits there are in the way of increased efficiency. The obvious goal is direct production of "light without heat," by which is meant producing only the rays of wave-lengths which affect the eye. The firefly appears to succeed in this. The radiation is obviously not that of a hot body, any more than the phosphorescence of jelly fish or microbes or phosphorus. It has been suggested that, though the radiation is not that of a hot body, it can only be produced at the efficiency which a hot body giving the same colour would give. Personal discomfort would prevent the vainest firefly from generating more than, say, 0·1 watt per square centimetre of cooling surface, and anyhow the insect appears to develop no appreciable heat.

There is no thermo-dynamical reason why electrical energy should not be converted directly into radiation of any wave-length without loss; I do not know if there is any molecular impossibility, but apparently our limits are practical—that is to say, it may be done, but we have not yet hit on the way of doing it. The vacuum tube appears to be a means of converting electric power direct into radiation. The Cooper-Hewitt lamp, for instance, gives an efficiency of about three candles per watt, or something like 0·6. All these figures as to light are a little vague. Unfortunately the light is of a very bad colour. It is very actinic, but the wave-lengths are too small. One method is to degrade the light by making it act on silk dyed with matters which lower the radiation to a redder colour by fluorescence.

The Arc Light.

The arc has been very fully studied in some directions, and not in others. Most makers of arc lamps seem to devote their whole attention to the mechanism, and look upon the arc merely as a hot gap that has to be preserved by suitable apparatus. Many lamp makers, on the

[1] See Note D, p. 39, "The Standard Candle."
[2] See Note E, p. 39, "Inverted Ratios."

other hand, have records of exhaustive experiments on the relations of the pressure, current, and light with different carbons; but they are very seldom published. On the other hand, an enormous amount of laborious experiment on such points as these is available,[1] and on the back electromotive force of the arc.[2] The physics of the arc, an exceedingly difficult branch of study, has not received much systematic attention yet. The crater of an arc is, no doubt, heated to the point of volatilisation of carbon at the pressure of the air. If other gases get at the crater, the vaporisation temperature would be less. (There is a small increase of pressure which I suggest is due to the electro-magnetic effect of a current localised in a conducting fluid. This may be neglected.) The crater may be rough, as carbon, though it softens, does not melt before volatilising, and it may be merely speckled with points at its volatilising temperature, so that its brightness is not uniform. But there are so many anomalies about the arc that one cannot say anything definite with safety. For instance, if the temperature is limited by the vaporisation of carbon, what must be the specific heat of vaporisation of carbon? Where does the vapour go to, and what happens to it in an enclosed lamp? In condensing into smoke it should give light of the same colour as the crater. If it has an enormous specific heat, it ought to raise the other pole to crater temperature where it condenses. If it is a light gas, a large portion of its specific heat of vaporisation may go to external work. Most of the upper carbon is burnt away by external air; if a pencil to match the crater is volatilised it does not account for much power. If the vapour is very light, there must be large volumes from the upper carbon. Then what conducts? Carbon vapour alone, or mixed with a little monoxide or nitrogen, is a very good conductor at these temperatures. Does that go to show that carbon vapour dissociates like iodine or chlorine, etc.? The whole question of the physics of the arc deserves far more careful study than it has yet received, but the work is surrounded with difficulties and is really a branch of the theory of the passage of electricity through gases, a matter of the greatest scientific importance somewhat out of our way as practical electrical engineers. But as engineers in the broader sense we are as much interested in questions of recondite physics as of costs of generation.

Looking at the arc as analogous to a vacuum tube with no vacuum, but very hot and very rarified gases instead—a difference in degree, not in kind—the question arises whether we can get direct conversion into radiation without intermediate heating. The enclosed arc seems to give us something of this sort. It is difficult to see what goes on inside the inner globe, but the arc itself, apart from the crater, seems to give more light. The efficiency of an enclosed arc is much reduced, however, by the deposit and globes. Hot vapours, such as that of metallic salts in the Bunsen flame, give out light by direct action, not because they are hot, but by some chemical change, and this holds good of vapours in vacuum tubes, and doubtless also in the arc. In an

[1] See, for instance, *The Electric Arc*, H. Ayrton, a valuable epitome of the work done on the arc lamp up to the present time, including the authoress'.

[2] See Note F, p. 39, "Back Electromotive Force of the Arc."

enclosed arc the carbon vapour instead of combining with oxygen may first condense at the temperature of the crater, forming a luminous envelope round the arc itself. By mixing suitable salts with the carbons we may thus expect to get electrical power converted directly into radiation. It has long been known that adding sodium salts to the carbons increases the light, perhaps without improving it, but such experiments have been carried out rather empirically, and apparently without any distinct idea of direct production of light. Recently great attention has been excited by the Bremer arc lamp, which owes its effect to the addition of salts to the carbons. Another recent development is the arc between pencils of oxide, such as zirconia. This arc, which was tried, if I remember right, about 1897, has come to the front again. It may depend simply on high temperature, or on small amount of shadow from the lower electrode; or it may be that zirconia volatilises and condenses as a luminous cloud outside the arc, giving a light like burning aluminium or magnesium, or the hot vapour may also be giving the zirconium emission spectrum in addition. I have not seen this light.

To sum up as to the arc light, we do not seem to have reached our limit as to light from pure heating, because we lose a lot of light into the opposite carbon. Many attempts have been made to expose the crater freely. But, far more important than this, I would urge that the arc is not necessarily a hot body radiator only, but that it may also convert electrical power directly into light in the space between the electrodes, and this gives a chance of rising more nearly to our theoretical limit of about five candles per watt.

The Incandescent Lamp.

This simple hot carbon wire in a bulb involves the most extraordinary physical complexities. A great many curious things go on inside the simple-looking globe. A good account of what is known—especially since he took the subject in hand—has been written by Dr. Fleming,[1] and the scientific manufacture of this interesting article has been fully described by Mr. Ram.[2] The incandescent lamp is a simple hot body radiator, and the limit of efficiency depends chiefly on the temperature of the carbon. As we are limited by the size of mains, we can only use pressures of 100 volts or 200 volts, and this limits us to carbon, or something of still higher specific resistance. The high pressure is bad for the lamp in every way. The carbon has to be longer and thinner, and therefore weaker, while the great pressure between the ends of the carbons gives rise to invisible discharges across the hot interior. The high pressure thus means that the surface of the carbon is worn away quicker, and that the carbon is thinner and less able to stand it. Inherently a high-pressure lamp is worse than a low, but the convenience as to distribution outweighs this disadvantage. The limit of efficiency of incandescent lamps is chiefly due to the variations of supply pressure. Carbon is beginning to soften at ordinary lamp

[1] *The Physics of the Incandescent Lamp.* [2] *The Incandescent Lamp.*

temperatures, and the upper limit is soon reached. So that, though a lamp may give a third or even half a candle per watt when run steadily, it has to be rated at a quarter to make it safe under ordinary conditions. The sensitiveness of the carbon lamp to pressure in its turn limits the practical variation of pressure of supply, and thus costs us very heavily in mains. If we had incandescent lamps which did not mind 20 per cent. pressure variation, we would have saved millions in mains in this country alone. Recently the demand for "ballast" for the Nernst lamp has led to the introduction, for that purpose, of little

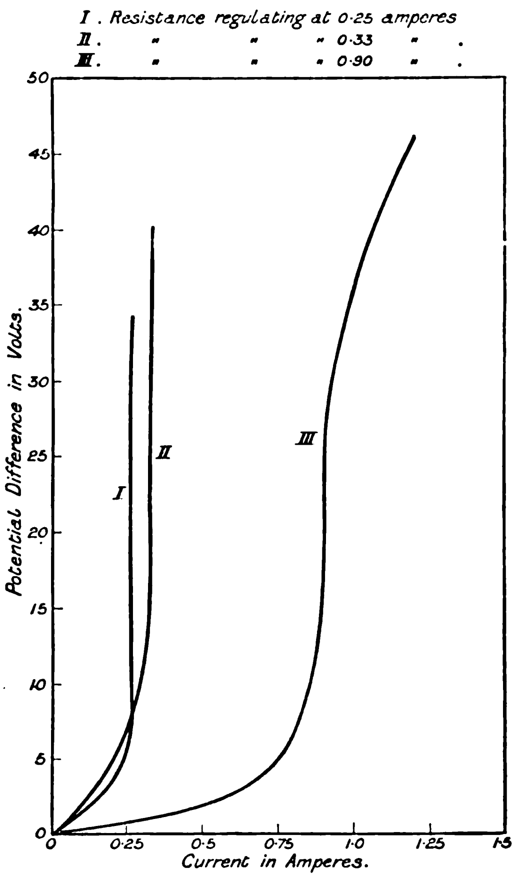


FIG. 4.—Pressure-current Curves for iron wire at critical point.

bulbs containing fine iron wire heated to the critical point. This "ballast" may be used in series with the incandescent lamp. Fig. 4 gives some curves taken by Mr. M. Solomon, who has been working at this subject. It will be seen that a small resistance will allow a lamp

to be run nearly at its maximum safe efficiency in spite of pressure variations, while a larger resistance will enable lamps to be run off tramway and other varying pressure circuits with good overall efficiency.

Other materials have been proposed instead of carbon. A great deal of work has been done on metals, but they have the great fault of low specific resistance. Even osmium seems unlikely for 200 volts. The specific resistance of metal goes up very quickly near the melting-point, but even then it is too low. I have worked a good deal at this problem, but unsuccessfully so far. Most of the metals generally called infusible are not nearly refractory enough. It is quite easy to melt such things as tungsten and molybdenum into globules at the temperatures necessary for high efficiencies. To oust the carbon lamp a great advance in temperature is necessary. I have found a metal that seems refractory enough, but it has too low resistance, and there are very serious difficulties in making wires of it. It would seem that black oxides ought to make good filaments. Most of these substances melt easily. They conduct when first made, and go on conducting when hot. But, if then allowed to cool, it will be found that they have undergone a change and no longer conduct. The black or brown oxide of vanadium is a good example of this.

The idea of making lamps of carbides has become very fashionable lately. People have put oxides into carbon for the last twenty years. The old idea is to get hold of an oxide that radiates more light at a given temperature than it ought to, which is itself a fallacy, while the idea of oxide in contact with carbon is chemically absurd. There is no oxide irreducible by hot carbon. The carbides are not by any means all refractory. Some are, though, but there are immense difficulties in making carbide lamps. I have made low resistance carbide lamps which stood high temperatures, but that is a very small step on the way. Mr. W. H. Story has gone on with this, beginning where I left off. After two years' solid work he has made no carbide lamps, but I believe he will eventually. To make a fine filament of an infusible material, which can be made only at electric furnace temperatures and which is generally decomposed by moist air, is not an easy task. It is easy to think you have made a carbide lamp by incorporating an oxide in the filament material, but the resulting filament is generally mostly if not wholly carbon. What happens to the metal under the circumstances is rather a mystery. There is, however, a chance of enlarging our limits in incandescent lamps of the ordinary kind, but it seems strange that the melting points of all known materials should suddenly reach a higher limit. Assuming the Stefan-Boltzmann law for ordinary light radiations, the fact that the efficiencies of refractory bodies all reach limits of the same order shows that the most refractory bodies melt at about the same temperature, somewhere in the neighbourhood of 3,000° A. As melting points are dotted along the temperature scale from 16° A. for hydrogen and something lower, not yet determined, for helium and bodies ending in "on" up to about 3,000° A., we might expect some to go up to 4,000, 5,000, and so on. Whatever the inter-molecular forces may be that bind the particles to make

solids, the vibration forces due to temperature seem to overcome the greatest at about 3,000.

Instead of an ordinary conductor, Nernst uses an electrolyte which stands a higher temperature. The conduction is electrolytic, as can easily be shown, but there are many curious phenomena, many of them so far unexplained, in the Nernst lamp. The efficiency of the Nernst lamp is about 0·6 candle per watt. It was at one time supposed to owe its efficiency to selective emission, but there is no reason to doubt that it is a pure temperature radiation. It might be said that as a vacuum tube and a Nernst glower both conduct electrolytically, both being transparent, the Nernst may work by direct conversion of electrical power into radiation; but it does not work in this way, at least not mainly. Emissivity seems to vary with temperature in the case of solids and liquids. A transparent, that is to say a non-absorbing, gas does not radiate when heated, but a transparent solid emits when hot even those rays which it does not absorb when cold. Recently some writers have treated the ordinary carbon filament as being transparent when hot. If it were transparent it would not follow the cosine law, but it also would have to conduct electrolytically. The idea of carbon conducting electrolytically is too extreme to be entertained. It is difficult to say how the idea of the transparency of hot carbon has arisen. Perhaps carbon does not behave as a "black body" because it is not quite black, and because its index of refraction is widely different from that of a vacuum, so that it may depart from the law of cosines and look brighter in the centre, as if transparent. The Nernst lamp, however, gets us nearer our limits both by high temperature and high pressure, so that it pushes out the limits of constant pressure distribution. One difficulty in the electrolytic lamp is to get the material to conduct at a low enough temperature, and to stand a high temperature too. The Nernst lamp is essentially zirconia, which stands a high temperature. A little basic oxide of the yttria group is added, and there is probably formed a portion of zirconate of these metals, which is fusible enough to conduct at a lower temperature. This subject needs elucidation, as the zirconates are probably like the silicates, forming a long series. Moreover, zirconia and yttria in the proportions for simple zirconate form a very infusible material. The whole subject is very obscure. We cannot say we have got anywhere near our limits of high temperature efficiency of running, low temperature in starting, or high pressure in the electrolytic lamp.[1]

Electric Heating.

The limit of electric heating is clearly purely financial. To convert heat into other energy with a very small efficiency and to send it out by expensive cables and then to degrade the energy down to heat again is obviously much dearer than burning coal or gas direct. But in many domestic cases the convenience is so great that the limit is not so low as

[1] See Note G, p. 41, "Efficiency and Temperature."

might be thought, and electric heating for cooking and other domestic uses may develop considerably. The electric arc and incandescent lamps are essentially cases of electric heating. By far the most important use of electric heating is the furnace. Here the temperature available is only limited by the volatilisation of the electrodes, and this enables us to get temperatures otherwise unavailable, so that we can get chemical actions which are impossible at lower temperatures, either because they are endothermic or because the materials do not come into chemical contact at ordinary temperatures. It is impossible to say what our limits are in the electrical furnace. Probably the temperature is limited by the volatilising of carbon. The products are not limited to endothermic compounds, the furnace is useful for the reduction of metals and phosphorus; and for melting glass and, it is hoped, silica for optical and laboratory purposes, and perhaps for cooking utensils and evaporating pans and crucibles in chemical engineering and metallurgy.

Railways.

It is almost absurd to begin to consider the limits of the use of electrical transmission on railways at this date. The future of electric railways, electric tramways, and automobiles is rather a matter of vague conjecture and picturesque prophecy. Tubes are multiplying rapidly, and railways are putting down electric transmission on suburban lines in Europe and the States. On short lines with many stops we have to contend with inefficiency at starting. On long lines there is difficulty of transmission or cost of transformation and difficulties of collection. We are very much handicapped, or limited by the want of a suitable variable speed-gear for large powers. For short lines the ordinary tramway system is used and many schemes have been proposed. Three-phase motors, either in cascade with high primary pressures, or arranged simply, are being tried and have many advantages. Various arrangements of motors have also been discussed or tried. Series distribution has been proposed but never tried. Though it superficially resembles series tramways it differs essentially in the switches being a long way apart, and not worked by the train, and having constant current variable speed generators. One difference makes it practical as far as the switches go, the other efficient. But a variable speed-gear would solve the difficulty very much better than any of these schemes. We could then have simple alternating circuits with all the consequent ease of transmission and transformation, and the trains could go at suitable speeds with high efficiencies throughout. The Leonard is an electrical variable speed-gear, but it is expensive and not very efficient. A few mechanical gears have been proposed to work with synchronous alternating motors. The most obvious arrangement is a system of pumps. Air pumps with a reservoir have been proposed. A system of oil pumps of variable stroke is also in use to some extent for automobiles.[1] But machinery of that sort practically means that an electromotive must

[1] See Note H, p. 41, "Variable Speed Gear."

have not only a motor of say 1,000 kw., but what amounts to two sets of motion work. This must mean serious expense. We may therefore say that we are limited by the want of either a variable speed simple alternate-current motor, or a simple variable speed-gear capable of transmitting a very large torque, and packing into an engine. A recently developed scheme is the use of low-frequency alternating currents with laminated series-wound motors. This solves the difficulty, but at the expense of large idle current, induced pressure in short-circuited armature coils, large expensive and inefficient transformers, and the ordinary disadvantages of the series-motor on constant pressure. This plan is well worth serious study.

The collection of large currents at great speeds has long loomed as a limit. The published accounts of experiments at Zossen would lead us to suppose there is no trouble on this score. Still it is a difficulty many engineers fear.

In electric tramways there is no limit in sight. The power can be sent over any distance desired, and there seems to be no limit to the people who want to travel on electrical trams. The question of electrolysis is rather that of a limit to the duration of pipe companies' property. It is a very difficult question. Though the threatened effects of electrolysis have no doubt been exaggerated it is at best a question of degree, and the ingenuity of engineers is continually reducing the chance of damage. It has recently been urged that frequent reversals of polarity of the system reduces the electrolysis very considerably.

Electrolysis.

This is a branch of industry in which it is very difficult to tell our limits. In electrolytic copper-refining our limit is that of the copper wanted. Our electrolytic industries suffer mostly from the limits of intelligence of the investing public. It is assumed that we cannot do electrolysis in England because we have no water power. This is only an excuse for inactivity. As already explained, we can do just as well without water power. A blast furnace is much more valuable than a waterfall of similar power, because it is near coal and in an industrial district. Moreover, as already explained, the cost of electrical energy is a small portion of that of most electrolytic products. At first electrolysis was to be applied to copper-refining. Then to caustic soda. The output of electrolytic caustic is really rather limited by the demand for bleach. What is urgently wanted is some other way of storing and carrying chlorine. Steel bottles and compression plant are an unsatisfactory solution. What are the limits in the way of electrolysing fused salt? They are all incidental limits. The containing vessel is a difficulty. Sodium vapour attacks all silicates. Sodium distils near the temperature of fused salt. If not volatilised it forms a conducting bridge from the cathode. It attacks iron, though slowly. Hot porcelain and earthenware conduct electrolytically—as, by the way, the maker of electric frying-pans knows—hot chlorine attacks metals, even when dry, and hot carbon cannot be exposed to the air. In addition sodium and perhaps chlorine are soluble in hot salt, and traces of

sulphate in the salt act as carriers as sulphate and sulphide. I could a tale unfold if I read out laboratory notes of sodium experiments on a fairly large scale. The difficulties are all incidental, though, and I have little doubt electrolytic sodium at a few pounds per ton will be in the market soon, and will affect profoundly many chemical and metallurgical industries. I would like an opportunity to continue experiments myself, but others will, I feel certain, soon succeed.

In metallurgy electrolytic solution processes are in use or on trial for the more valuable metals, such as copper and nickel. The reaction between chlorine and metallic sulphides at high temperatures brings the whole domain of sulphide ores under our sway. Thus a sulphide, say galena, is treated with chlorine, which gives off the sulphur as sulphur, which is condensed and sold, making chloride of lead. The silver is extracted by stirring with a little lead, and the fused salt is then electrolysed, yielding pure desilverised lead and chlorine. The process is thus self-contained, yielding sulphur, lead, and silver. It is specially applicable to mixed refractory ores which are now nearly valueless and very plentiful, and contain much metal content, such as the mixed lead-zinc sulphides of America or Australia. These reactions have been proved on the large or ton scale, and there is no technical difficulty. Unfortunately mine people are somewhat ignorant of electrical matters, and it is exceedingly difficult to get them to understand or appreciate a process like this, capable though it may be of paying good dividends on very large capitals indeed.

In all these metallurgical extractions we may roughly take the cost of energy as a farthing per kilowatt-hour for steam, and half that for gas. Allowing a rough average pressure per cell, we may take it that electric energy costs £100 per tonne- or ton-equivalent by steam and £50 by gas. That would be £3 a ton for zinc, £1 for lead, £3 for copper, and iron by steam, and half these figures by gas power. This means that the metallurgy of all the sulphides, except perhaps iron, is within our grasp. It may pay to make a pure iron, free from phosphorus, silicon, manganese, and carbon at something under £10 a ton from pyrites ores (which may also contain zinc, nickel, copper, etc.), and then add exactly the desired amount of other constituents or "physic" to produce with accuracy steels of special grades.

But our limit in electrolysis in this country is almost entirely human inertia. Commercial and financial people do not understand it, and fight shy of it. But our technical people are nearly as bad. The pure physicist, as a rule, takes no interest in electrolysis or physical chemistry, and thinks it belongs to the chemical classroom on the other side of the passage. The chemist thinks it is higher mathematics and will have none of it, the mathematician thinks it may be an exercise in differential equations; but they are all agreed that it is a sort of Continental fungus which flourishes with no roots, and that it is beneath the attention of a scientific man to know enough about it to give a reason for the broad statement that it is all nonsense.

I have now tried to bring before you the various barriers which appear to bar our progress in various directions: it is for you to get over those you can, and to get round the rest.

Note A.—MUTIVITY.

The term motivity was introduced by Kelvin (*Phil. Mag.* 1879, Math. and Phys. Papers, I.), but is not used much now. The expression "Available energy" is well known and clear, though through an obvious slip in the first edition of Maxwell's "Heat" it was called, but not confused with, "entropy." The term Motivity suggests,

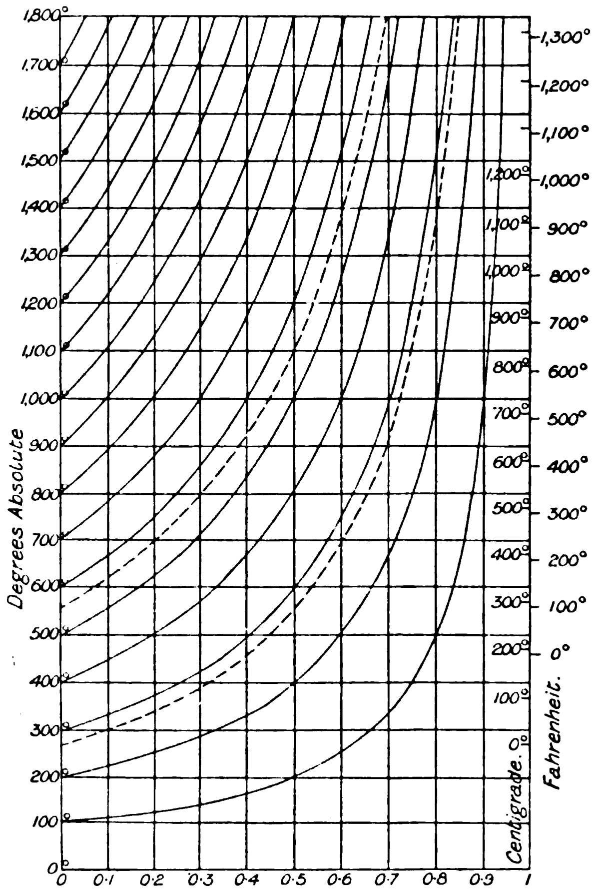


FIG. 5.

according to the modern fashion in nomenclature, a specific quantity, but I have no right to use it in a new sense. I therefore suggest "mutivity," which is a contraction for "mutativity," to denote the changeability or convertibility of the heat into other forms of energy. The mutivity is thus a number equal to $(\theta_1 - \theta_0)/\theta_1$, which is less than unity, so that the mutivity is the available energy per joule. The energy integral of the mutivity is thus the available energy. The curves Fig. 5 give roughly the mutivity corresponding to various

temperatures. Thus if one wants to find the value of some heat at, say, 600° absolute with a lower limit of 200, the line starting from 200 is followed till it cuts the horizontal 600° line. The other ordinate gives the mutivity 0·66.

Note B.—COMMON SENSE SCIENTIFIC UNITS.

To talk of boiler pressures in megadynes per square centimetre may seem strange. We, the electrical engineers, have an almost perfect scientific system of units so that the quantities hang together in a sensible way. No one who once understands the C.G.S. system ever wants to work any other. If a man never wants to apply thermodynamics to anything but British steam engines, and never wants any foreigner to read his work, and never wants to know what is done outside this small island, the English system may suit him if his time is of so little value that he does not mind a tangle of useless coefficients. If, however, any one wants to do quantitative work—and all such work should be quantitative—the ordinary units and tables in thermodynamics are terrible. In England we measure heat in thermal units with no name, and energy in foot-pounds, and power in horse-power. Our thermometer is graduated without any apparent relation to anything. It has been said that its zero is the temperature of ice-cream, and its 100 that of the fevered patient who consumed it. Mr. Ram has pointed out that each degree really corresponds to the expansion of mercury by a ten-thousandth part. Our pressures are in pounds per square inch less the magic number 14·6967, but we take condenser pressures as the difference between the number of inches of mercury read and 29·92. These measurements involve a huge amount of unnecessary arithmetic every time they are used. This means waste of time and chance of inaccuracy. The French are by no means beyond reproach. Their pressures are either in atmospheres, atmospheres less one, or in millimetres of mercury. The Centigrade scale is just as absurd as the Fahrenheit. Even with 273 added, it has no numerical relation with anything. Some day we will perhaps have an absolute scale. But practically all thermodynamical workers fail to realise that heat is really energy, and have a special unit of heat depending on the specific heat of water which has nothing to do with anything else. We, as the most scientific of the engineers, ought to use our own scientific and rational units, so that the horse-power, foot-pound, pound per square inch, poundal, caloric, British thermal unit, inch of vacuum, and all the thousand and one silly weights and measures may be helped into the limbo of disuse.

Note C.—ENTROPY.

There is an unfortunate misconception as to the nature of the function entropy in most treatises on the steam and gas engine, and in the use of the θ,ϕ diagram. Clausius defined entropy so that—

$$\int \frac{dH}{\theta} < \phi.$$

The whole idea of entropy is that in every change in nature it must increase, otherwise the change cannot occur. In the hypothetical but impossible case of reversibility—

$$\left(\int\right) \frac{dH}{\theta} = 0,$$

where the brackets mean that the integration is round a closed cycle, and—

$$\int \frac{dH}{\theta} = \phi.$$

The study of reversible changes occupies most of the space in books on thermodynamics, just as the study of frictionless mechanisms throws light on engineering problems; but, though it is numerically correct in the limiting and purely hypothetical case of reversibility, the equation

$$\int \frac{dH}{\theta} = \phi$$

as a definition of entropy is fundamentally wrong. It gives a wholly wrong notion of entropy. The temperature entropy diagram was, I believe, first brought forward by Gibbs (Trans. Connecticut Acad. II. 1873, p. 309). This paper is difficult to get in English, but a translation is accessible in "Thermodynamische Studien," Gibbs, pub. Engelmann. Here the author is definitely dealing mainly with hypothetical reversible processes and the properties of fluids, and such things as perfect gases, and any one reading the paper alone would get a wrong idea of entropy; but it was rather meant to clear the ideas of students, and did not affect engineers. We really owe the practical use of the entropy diagram, and the insight we have gained through it in spite of the confusion as to entropy, to Macfarlane Gray. In his papers, "The Ether-pressure Theory of Thermodynamics" and "Rationalisation of Regnault's Experiments" (Proc. Inst. Mech. Engin. 1889, p. 379), the definition of entropy is as faulty as Gibbs'; but he again is discussing the properties of steam and dealing with reversible processes, so again there is no numerical error. In discussing the θ,ϕ diagram of an engine, however, it is usual to define the entropy by the equation $d\phi = dH/\theta$, which is wrong, and to lay down that the area of the θ,ϕ is equal to that of the p,v diagram (divided by the mechanical equivalent of heat). This incorrect definition has no doubt given rise to the notion that entropy is the factor of heat corresponding to temperature. I think Zeuner first called entropy "heat weight," a confusion of thought which is constantly cropping up. The whole object of engine analysis is to trace irreversible changes. If the diagrams were of the same area, after multiplying by the wholly unnecessary coefficient, the engine would be reversible and perfect, and there would be no use in investigating it. The badness of an engine in its way of using its working fluid should come out in terms of the excess of the θ,ϕ over the p,v diagram. In thermodynamics there is a constant tendency to confusion between the working substance and the reservoirs. Entropy is a function that essentially concerns the reservoirs. Thus a perfect engine would allow no increase of entropy. If an engine and a boiler were perfect, the entropy taken in by the water from the hot gases would be equal to that given to the condenser water. There are various increases of entropy in practice. The most important are increases of entropy due to adding feed-water below the boiler temperature, wire drawing steam, heating the air by convection and radiation of steam pipes and engine, conduction between cylinder walls and steam, conduction through cylinder walls from jacket, sudden expansion into condenser, and mechanical friction throughout the mechanism. The importance of each growth of entropy depends on the temperature. The temperature integral of the irreversible increase of entropy would be an area on a real θ,ϕ diagram. The total area of the θ,ϕ diagram would then exceed that of the work of the engine (or of the p,v diagram if the mechanical friction is excluded) by this area, which would represent the badness of the engine. To give a clear idea of the value of this loss the mutivity

should come in as a coefficient right through. This is done graphically by cutting off the bottom of the area. We should therefore localise all increases of entropy in an engine, and then try to prevent them.

It may be urged that the definition of entropy with which I find fault is given not only in engineering text-books, but that it occurs in nine out of ten treatises on mathematical physics. That is so; most writers define entropy incorrectly. As the mathematical treatment of reversible processes naturally occupies most of their attention, an incorrect definition gives no quantitative error until irreversible processes are considered. The mathematical physicist then generally, perhaps consciously, rises to accuracy, but sometimes he does not. Adiabatic and isentropic are thus also defined as synonymous. The isentropic or curve of constant entropy does not coincide with the adiabatic or curve of no passage of heat except in hypothetical reversible changes. On a p, v diagram the adiabatic curve may be anywhere between the isentropic and the isothermal coinciding with either in a limiting case. Unfortunately also entropy fell among pedagogues. The pedagogue takes $d\phi$ as a leading illustration of an exact differential. It is extraordinary that out of the whole domain of physics he should select the one differential whose conspicuous characteristic is that in nature it never is exact. Perhaps he has a fellow feeling for it. It is sometimes stated that if the quantity is a single valued function of the co-ordinates, its differential is exact, and that is what exactness means, which is also inaccurate. This not only shows that it is infinitely easier to work with mathematical symbols than to get a clear grasp of their physical meaning, but it emphasises the extreme difficulty and slipperiness of thermodynamical work in particular.

Note D.—The Standard Candle.

The standard candle, which ought to give a light of 4π, is about as absurd as the horse-power. The candle and the horse are about equally nearly obsolete, and the candle is about as likely to give a candle-power—or 4π units of British light—as a horse to give a horse-power. The horse has one advantage over the candle: he is not inextricably mixed up with the 4π controversy, and well-meaning people do not try to rationalise him as a unit.

Note E.—Inverted Ratios.

There is a curious tendency among engineers and other scientific men to get ratios wrong. People talk of efficiencies in "watts per candle"; "pounds of steam per horse-power-hour," a specially barbarous unit; insulation in megohms per mile: specific resistance in microhms per cubic centimetre; and muzzle velocity in foot-seconds; while elasticity is defined so that perfectly elastic means absolutely rigid. The "candle foot" and "candle metre" or "carcel metre" are now coming in to add to the unnecessary inaccuracy and confusion. It is sincerely to be hoped that we soon have light units in terms of watts and temperature of radiation, so as to fit into the C.G.S. system.

Note F.—Back Electromotive Force of the Arc.

Ohm's law, $C = E/R$, is really a statement of a physical fact, namely, that if the other physical conditions remain constant, the ratio of C and E is invariable. It is not a mere definition, though it is a definition too. But if the physical conditions alter with variations

of C, there is only left a definition of R as being equal to E/C. We cannot by any measurements of E and C find out anything about the nature of R. If we choose we may write $C = E/R + e/R$, where e is defined as a pressure which may be negative, and R is defined as a resistance. Any attempt to determine R and e from measurement of C and E is merely an attempt to solve a single equation with two unknowns, which is absurd. If two or more sets of readings of E and C, E^1 and C^1 and so on are taken, a fancy definition of R and e may be given, so that $C = (E + e)$ R, $C^1 = (E^1 + e)$ R, etc., and if many readings are approximately consistent with constant values of e and R they may be called electromotive force and resistance, but they are only fancy names, and have no physical meanings. If many readings are inconsistent with constant values of e and R some qualifications may be given to them, but still there is no physical knowledge obtained. All the measurements of E and C in the world can only give E and C; we may give any names we like to functions of E and C, but they give no further knowledge. They are really round-about methods of stating the values of E and C. The back electromotive force and resistance of the arc are thus, from this point of view, mere matters of fanciful definition. A huge amount of labour has been devoted to trying to determine the resistance and back pressure of the arc in terms of E and R. I would urge that all this is an attempt to solve a problem which does not exist, and the waste of time and trouble is due to looseness of thought in not clearly defining the terms "resistance" and "back electromotive force" in cases where Ohm's law is no longer a law stating that a certain physical quantity is not varied by changes of current, but a definition, which if accepted as $C = E/R$, gives R merely as a ratio of C and E, or if modified to $C = (E + e)$ R involves two unknowns in one equation. Not only have innumerable experiments been made measuring C and E, but their ratios of relative increase are taken as if they gave further information. This involves exactly the same fallacies. Many of the methods involve making a change, say in C, and assuming the arc has not had time to change accordingly, but the arc is too quick. The various ingenious arrangements with alternating or telephone currents superposed on direct, or direct superposed on alternating are of the same type. They combine the argument in a circle as to the definition, with an attempt to deceive the arc by taking measurements before the arc has time to feel the changes due to change of current. These considerations are urged with the view of possibly saving unprofitable work. The first thing to do before trying to determine back electromotive force is to settle very clearly and definitely what you mean by back electromotive force, and by resistance. If they can be given in terms of any measurable quantities other than E and C, those other quantities are to be measured. But if they are only functions of E and C there is no use trying to solve one equation with two unknowns, and one is merely working back to his own definition, and not making a physical research. I urge this with diffidence, but at the same time with vigour, because we have an awful example before us in the "Seat of the Electromotive Force" in a cell. If people had started with a clear physical definition of what they meant by the seat of electromotive force, and if they had agreed as to a definition, not only in words but in idea, there would have been neither research nor controversy. We use the terms "resistance" and "electromotive force" so familiarly that we naturally assume we know what we mean by them. But that by no means follows.

From Ohm's law as a statement of a physical property of matter we get to regard resistance as a property in accordance with which $dH/d\theta = C^2R$; that is to say, resistance has come to mean a property

by which electrical energy is degraded directly into heat, an irreversible process, while an electromotive force with a current means reversible change of electrical or mechanical or other power, or *vice versa*. This difference, though I have never seen it formally stated, runs tacitly through science. Again, we may regard electromotive force as being produced only by lines of induction cutting the circuit, to take the crude conception. This is the same definition in another form; except that in the reversible interchange between chemical and electrical energy, magnetic induction is not generally considered. The behaviour of magnetic induction due to the movements and chargings and dischargings of ions has not been worked out in any publication as far as I know, but it ought to be. Thermo-electricity is worthy of study from the same point of view.

Taking these definitions and going back to the arc, it is clear that nearly all the power is spent at the crater. The drop of pressure may therefore be taken as being at the crater, so that the arc proper is nearly at the same pressure as the other carbon. If the change of electrical energy is directly into heat, as there is no reason to doubt, then it is due to resistance and not to back electromotive force. On the other hand, the radiation from the arc itself is probably due to direct conversion of electrical power into radiation; that is to say, the gas does not radiate light because it is hot,—gases at 3,000° C. do not radiate any light,—but because the current affects the particles in such a way that they produce light. There are thermodynamical reasons for treating radiation as heat, but as the energy is not in this case first degraded to heat to heat the gas, and then radiated because the gas is hot, the radiation is caused not by resistance, but by back electromotive force. The molecular movements, whatever they may be, involve magnetic induction increasing or decreasing in the interlinked circuit in such a way as to produce a back pressure, the power spent in overcoming this back pressure going out as a continuous stream of radiation. This back electromotive force must be very small—nothing of the order of 40 volts for instance.

Note G.—Efficiency and Temperature.

It is necessary to point out that the view that the efficiency of a radiating body depends on temperature only, and not on the surface, is not generally held by scientific men. Some eighteen years ago I believe I was a minority of one in holding that in an incandescent body, such as a lamp filament, the efficiency depends on the temperature only; and that the colour of light depends on the temperature only. Mr. Ram, in his book on the Incandescent Lamp, holds this view, but he is an old assistant of mine in lamp making; and we are still a small minority of two or more. My reason for holding this view was that it seemed to me that if a body with a special surface gave out light of a whiter or bluer colour, the phenomenon would be at variance with the second law of thermodynamics, and the surface would be doing the work of Maxwell's demon, not by letting through only the most rapid molecules, but letting through only the vibrations corresponding with them, which is much the same thing.

Note H.—Variable Speed Gear.

A variable speed gear has been invented by Mr. Hall for use in automobiles; but his gear is also applicable to electromotives. It consists of two sets of oil pump engines of variable stroke mounted in

a rotating frame. One set of oil pumps works on to a fixed axle, the other on to the driving axle, and the motor drives the frame round. If the frame goes at constant speed, the speed of the driving axle varies according to the strokes of the pumps. If they are equal, the engine goes at half speed. If the fixed axle pumps are at no stroke, and the moving axle at full stroke, the engine goes at full speed. The speed can thus be gradually varied from nothing up to full speed, and at full speed the efficiency is 1. At half speed the pumps are doing their

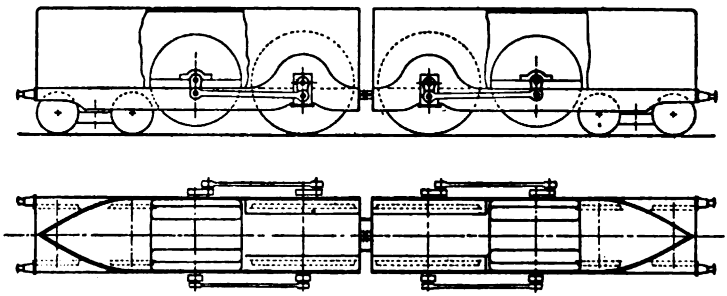


FIG. 6.

maximum power. If their efficiency is 0·9 the total efficiency is 0·95, and so on.

Mr. Hall purposes to use two gears and four motors. The driving axles are connected with the driving wheels by coupling rods. The electromotive is articulated in the middle to turn corners better. This

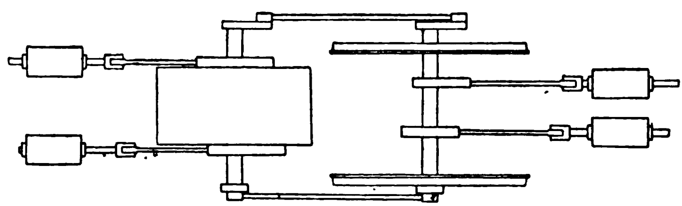


FIG. 7.

system allows the train to be run by high-pressure single-phase, constant-speed motors. At starting, on say double torque, the current is practically zero, climbing up to full current at half speed. The change is then made from constant torque to constant power, and the train gradually gets up to full speed with its normal current. In ordinary running the speed would be about nine-tenths of the maximum, to allow a margin, so that the oil pumps would transmit 0·1 of the actual power, or about 0·08 of the maximum power. Taking the pumps' efficiency to be 0·9 the loss is 0·008, or under one per cent. at ordinary speeds. This system thus allows the electromotive to exert any starting torque the motion work is strong enough to transmit, or the adhesion to utilise, while the motor only takes in enough power to run the mechanism round; and it allows the electromotive to run at any speed within designed limits, taking just the power needed; all this being done on

a single-phase alternating-current system of convenient frequency, with every facility for transmission over great distances and distribution, and energy return on stopping. The Hall electromotive is shown diagrammatically in Fig. 6.

The electric motor permits of another arrangement, however, in which the pumps do not rotate. The motor armature is on the driving axle, and the field magnets can revolve too. The field magnets work two stationary oil pumps with variable stroke. The oil works two more oil pumps which act on the driving axle, also with variable stroke. This mechanism has the same economical results as the Hall gear. It is shown in Fig. 7.

Mr. ALEXANDER SIEMENS: It is my privilege to-night to move,—"That the best thanks of the Institution be accorded to Mr. Swinburne for his most interesting Presidential Address, and that, with his permission, the address be printed in the Journal of the Proceedings of the Institution."

It is hardly necessary for me to add to the words of the motion, and I therefore simply move that the best thanks of the Institution be given to him for his address.

Mr. S. Z. DE FERRANTI formally seconded the motion, which was carried with acclamation.

The PRESIDENT, in reply, said: Gentlemen, I thank you very heartily indeed for the exceedingly kind reception you have given to my poor address, and for the great attention with which you listened to what I am afraid was a rather long, very dry, and technical address.

The PRESIDENT announced that the scrutineers reported the following candidates to have been duly elected:—

Associate Members.

Vittorio Giovanni Lironi.	Alejandro Voglino.

Associates.

Wm. H. Govier.	Frank Russell Seller.
George T. Rayner.	Frederick Turnbull.
Arthur Allen Saward.	George Arthur Webb.

Student.

George Wharton Hellicar.

The Three Hundred and Eighty-first Ordinary General Meeting of the Institution was held at the Institution of Civil Engineers, Great George Street, Westminster, on Thursday evening, November 27th, 1902—Mr. J. SWINBURNE, President, in the Chair.

The minutes of the Ordinary General Meeting held on Thursday, November 13th, 1902, were read and confirmed.

The names of new candidates for election into the Institution were announced, and it was ordered that their names should be suspended in the Library.

The following transfers were announced as having been approved by the Council :—

From the class of Associates to that of Associate Members—

John Henderson Mackail.

From the class of Students to that of Associates—

S. L. Cazeaux.
Donald Albert Hills.
Francis Ernest Pring.

Donations to the *Library* were announced as having been received since the last meeting from The Director-General, Indian Government Telegraphs ; to the *Building Fund*, from Mr. T. Cushing ; and to the *Benevolent Fund*, from Mr. W. H. Patchell, to whom the thanks of the meeting were duly accorded.

Messrs. D. H. Kennedy and A. Russell were appointed scrutineers of the ballot for the election of new members.

The PRESIDENT : I have now the pleasure to call on Sir Oliver Lodge to read his paper. But before doing so, I would remind this Institution that the last time we had the pleasure of hearing the lecturer he was Professor Lodge : now he is Sir Oliver Lodge. It makes no difference to us at all. We have known him for a long time, and no honour of this sort could raise him in the least in our estimation. But at the same time it must be remembered that it is a great honour. To estimate the value of such an honour as knighthood, you must multiply the knighthood by the man who receives it, and in a case of this sort we all know what the value is, because here it is. I now call on Sir Oliver Lodge to read his paper on "Electrons."

ON ELECTRONS.

By SIR OLIVER LODGE, F.R.S., Vice-President.

INTRODUCTION.

In Maxwell's *Electricity* published in 1873, section 57, the following sentence occurs in connection with the discharge of electricity through gases, especially through rarified gases :—

> "These and many other phenomena of electrical discharge are exceedingly important, and when they are better understood they will probably throw great light on the nature of electricity as well as on the nature of gases and of the medium pervading space."

This prediction has been amply justified by the progress of science, and no doubt still further possibilities of advance lie in the same direction. The study of conduction through liquids first, and the study of conduction through gases next, combined with a study of the processes involved in radiation, have resulted in an immense addition to our knowledge of late years, and have opened a new chapter, indeed a new volume, of Physics.

The net result has been to concentrate attention upon the phenomena of electric charge, and greatly to enhance the importance of a study of electrostatics. Not long ago Fitzgerald used chaffingly to speak of electrostatics as "one of the most beautiful and useless adaptations of nature"; and it was becoming the custom with teachers who felt that they must attend exclusively to the practically useful, and not waste their students' time on decoration and superfluities, almost to ignore, or at any rate to scamper through, the domain of electrostatics, and to begin the study of electricity with the phenomena of current, and especially of the connection between electricity and magnetism.

And certainly from the severely practical point of view, as well as from many other aspects, this part of electrical science remains the most important; but to him who would not only design dynamos and large-scale machinery, to him who in addition to the training and aptitude of the engineer possesses something of the interests, the instinct, and the insight, of a man of science, to such a one the nature and properties of an electric charge, at rest and in motion, constitute a fascinating study; for there lies the key to the inner meaning of all the occurrences with which his active life is so intimately concerned—there lies the proximate solution of problems which have excited the attention and taxed the ingenuity of philosophers and physicists and chemists since men began to escape from the struggle for bare existence—that most immediately practical of all occupations—and felt free to devote themselves, some to art, some to literature, some to the

accumulation of superfluous wealth, and some to the gratuitous pursuit of speculation and pure theory.

Your President, Mr Swinburne, realising that a society like this was sure to contain men eager to pursue their subject into some of the intricacies far removed from their immediately practical occupations, wrote and pressed me to come up and give an explanatory sketch of what had been done of late in the world of pure science towards the elucidation of the most familiar electrical processes; and with but little hesitation I consented, feeling sure that what the President urged would not be regarded by the Institution at large as out of place or unsuitable, though of my own motion I should never have thought of offering any such paper.

PART I.

First I must lay a basis of pure theory: we must consider the properties of the ancient and long known phenomenon called an electrified body.

Two substances placed in contact and separated are in general united more or less permanently by lines of force, the region between them being in a state of tension along the lines and of pressure at right angles. These lines have direction: they begin at one body and end at another, they map out a field of electrostatic force, and their terminations on one one or other of the bodies constitute what we call an electric charge. Electric charges are of two kinds, one corresponding to the beginning of the lines, the other to their ends. To one class of bodies, called insulators, the lines appear rigidly attached; whereas in another class they slip easily along, and are transferred from one such conducting body to another in contact with it, with great ease.

The tension in the lines tends to bring the ends together as near as possible, giving rise to what is observed as electrical attractions and repulsions.

In empty space it is probable that the only way of destroying such a field of force is to allow the two bodies to approach each other, and thus shorten up the lines to nothing; though even so it is not probable that the charges are destroyed, but only approach so close that they have no external effect at any moderate distance. When matter is present, however, it may be able to assist this collapse of the lines in various ways, giving rise to the various phenomena of conduction and of disruptive discharge.

If one of the two oppositely charged bodies is sent away to a considerable distance, while the other is isolated and regarded alone, the lines of this latter start out in all directions in nearly straight lines, giving rise to the simple notion of a single charged body,—a thing which is no more really possible than is a single magnetic pole. The other ends of the lines must be somewhere, though they may be so far away as to be spoken of as, for all practical purposes, at infinity.

Now consider how far this field of force belongs to the body, and how far it belongs to space, that is to the ether surrounding the body The body is the nucleus whence the lines radiate, but the lines them-

selves, the state of tension and other properties which they represent and map out, do not belong to the body at all; at each point of space there is an electric potential, and this potential represents something occurring in the ether and in the ether alone.

A Charged Sphere.

Picture in the mind's eye such a charged body, say a charged sphere, and let it change its position; how are we to regard the effect of the displacement on its field of force? Nothing in physics is more certain than this, that when a body moves, the ether in its neighbourhood does not move. The ether, in fact, is stationary: it is susceptible to strain, but not to motion; it is the receptacle of potential, not of locomotive kinetic energy.

The effect of the motion of the body, then, is to relieve the strain of the ether at one place and to generate it at another; the state of strain travels *with* the body, but *through* the ether.

Regarding the matter from the point of view of the ether, we might say that the field of force is constantly being destroyed and regenerated as the body moves. Regarding it from the point of view of the moving body, we should say that it carries its field with it.

The question now arises—and it is far from being an easy question—what sort of occurrences go on in the ether when this decay and regeneration of an electrostatic field is occurring, or when a field of force is moving through it? Can it adapt itself instantly to the new conditions, or does it require time? This matter has been studied, closely and exhaustively, by Mr. Oliver Heaviside.

Fix the eye upon a point a mile distant from the body; does the information about the motion of the body reach that point instantaneously, so that all the lines of force move like absolutely rigid spokes, every part simultaneously: and if so, how is the communication carried on so that the distant parts of the medium can be thus instantaneously affected? Or does the disturbance only arrive at the distant point after the lapse of a small but appreciable time; in other words, has there to be an adjustment to the new conditions—an adjustment which reaches the nearest parts first and the further parts later; and if so, what additional phenomena can be observed during the unsettled period?

The answer is that during the motion of the charged body, and even after the cessation of its motion, until the disturbance has had time to die away and everything to settle down into static condition again, the phenomena of *magnetism* make their appearance: a new set of lines of force quite different from the electrostatic lines (although they, too, exhibit a tension along them and a pressure at right angles) come into temporary being. These do not originate at one place and terminate at another: they are always and necessarily closed curves or rings, and in the present simple case they are circles all centred upon the path of motion of the charged body. At any point of space there are now three directions to consider: (1) there is the original direction of the electrostatic field—the original electric line of force; (2) there is the direction of the motion—that is, a direction parallel to the movement

of the charged sphere; and (3) there is the direction at right angles to these two; this last being the direction of the magnetic lines of force—the direction of the magnetic field.

I spoke of the magnetic field as temporary, but that is on the assumption that the charged body is merely displaced, moved from one position to another; if it is not stopped, but keeps on moving, then the magnetic lines continue as long as the motion lasts. Its strength at any point r, θ, is—

$$H = \frac{eu}{r^2} \sin \theta.$$

If we are asked whether such a magnetic field is weak or not, I have to reply that that depends entirely on how strong the charge is and how quickly it is moving. There is, in my opinion, no other kind of magnetic field possible; and so if ever we come across a magnetic field which we feel entitled to consider "strong," we must conclude that it is associated with the motion of a very considerable charge at a velocity we may properly style great. But certainly it is true that for any ordinary charged sphere moving at any ordinary pace—even supposing that it is a cannon-ball shot from the mouth of a gun—the concentric circular magnetic field surrounding its trajectory is decidedly feeble. Feeble or not, it is there, and to its existence we must trace all the magnetic phenomena of the electric current.

For just as there is no electrostatic field save that extending from one charged body to another, so there is no electric current except the motion of such a charged body, and no magnetic field except that which surrounds the path of this motion.

The locomotion of an electric charge *is* an electric current, and the magnetic phenomena surrounding that current are believed to be the only magnetic phenomena in existence. If any other variety is possible, the burden of proof rests on those who make the positive assertion.

One more statement:—

While the charge is stationary everything is steady, and we have an electric field only.

While the charge is moving at constant speed the current is steady, and we have a steady magnetic field superposed upon a steadily moving electric field, and a certain conveyance of energy in the direction of the motion.

But what about the intermediate stages, the stages of starting and stopping; what is the condition of things after the charge has begun to move but before it has attained a constant speed, and again when the brake is applied and the speed is decreasing, or when the direction of motion is changing? What phenomena are observable during the epoch of acceleration or retardation of speed or curvative of path? Something more than simple electrostatics and simple magnetism is then observed.

We get the phenomenon of induction—the generation of an induced E.M.F., of value at any point equal to the rate of change of the lines of magnetic force there. There being no conductor, this E.M.F. will

propel no current, but it will represent an electric force which was not there before, and in a new direction, perpendicular to the direction in which the growing magnetic lines are moving, which is outwards from the charge. Consequently the new or induced E.M.F. points in the direction of motion, though in the sense opposed to any change in it; and the effect of its superposition upon the magnetic field is to cause a certain small transmission of energy in a radial direction out and away from the accelerated charge. Some energy therefore flashes away with the speed of light, though in ordinary cases an exceedingly small amount.

It is from an electric charge during its epochs of acceleration or retardation that we get the phenomenon called radiation; it is this and this alone which excites ethereal waves, and gives us the different varieties of *light*.

The energy radiated per second is $\frac{2\mu e^2 \dot{u}^2}{3v}$,

where v is the speed of light and $\dot{u}$ is the acceleration of the charge e.

Thus, or rather by means of a very extensive development of these fundamental ideas, are all the phenomena of electricity and optics summarised, and, so to speak, accounted for.

Electric Inertia.

Whatever a charge may be, and whatever the hydrodynamic constitution of the ether, it must be able to maintain electric lines and magnetic lines, and to transmit energy wherever both sets of lines cross at right angles.

An accelerated charge is equivalent to a changing current, for $\frac{dC}{dt}$ may be written $\frac{d^2Q}{dt^2}$. Whenever a current changes we have an E.M.F. of self-induction set up equal to $L\frac{dC}{dt}$.

Considered from the point of view of a current constituted by a moving charge, this corresponds to a mass acceleration.

And the electrical acceleration is opposed by the E.M.F., just as the acceleration of matter is opposed by its mechanical inertia. The coefficient of the electric acceleration represents, therefore, an inertia term, and is properly called electric inertia.

By Lenz's law the effect of induction is always to oppose the cause which produced it. In the present case the cause is the acceleration or retardation of the moving charge, and so in each case this is opposed by the reaction of the magnetic lines generated by it.

Motion is opposed while it is increasing in speed, and it is assisted while it is decreasing in speed—an effect precisely analogous to ordinary mechanical inertia;—and therefore force is necessary, and work must be done, either to start or to stop the motion of a charged body. An extra force, that is, by reason of its charge. Whatever the inertia the body may have, considered as a piece of matter, it has a trifle more by reason of its being charged.

The value of this imitation or electrical inertia for the case of a charged sphere of radius a is

$$\frac{2}{3}\frac{\mu e^2}{a}. \quad \text{(See Appendix.)}$$

Since this is very important, I repeat :—

Just as a changing magnetic field affects an electrostatic charge, that is to say generates a feeble field of electric force, into the intensity of which the velocity of light enters squared in the denominator, so it is with a changing electric field, it generates a magnetic field proportional to its velocity of change; and if it is being accelerated, the magnetic field itself varies, and in that case generates an E.M.F. which reacts upon the accelerated moving charge, and always in such a way as to oppose its motion—by what is called Lenz's law, or simply by the law of conservation of energy : for if it assisted the motion, the action and reaction would go on intensifying themselves until any amount of violence was reached.

The magnetic lines generated by a rising current, that is by a positively accelerated charged body, react back upon the motion which produced them in such a way as to oppose it. To oppose it actually or elastically, not passively or sluggishly as by friction. The reaction ceases the instant the motion becomes steady : it is not analogous to friction therefore, but to inertia ; it is the coefficient of an acceleration term.

The magnetic lines generated by a falling current, that is by a negatively accelerated or retarded charged body, react oppositely and tend to continue the motion : thus here also we have a term corresponding to inertia. And the charged body may be said to have momentum by reason of its charge while it is moving. The value of the momentum is proportional to the velocity, so long as the velocity is not excessively great, and accordingly the inertia term is constant, and independent of speed, under the same restriction. It may therefore be considered to be in existence even when the charge is stationary, and thus it simulates exactly the familiar mechanical inertia of a lump of ordinary matter.

In an Appendix will be given the simplest form of the quantitative relations here indicated, and the inertia due to an electric charge will be calculated. It is to be understood that whatever inertia a material sphere may possess, considered as matter, it will possess more when it is charged with electricity, and this no matter whether the charge be positive or negative. The amount of extra or electrical inertia is proportional to the electrostatic energy of the charge : that is to say, it is proportional to the charge and its potential conjointly. Call the charge e, and the radius of the sphere a, the potential will be $e/\kappa a$ and the appropriate inertia is $m = \frac{2}{3v^2} e \,.\, e/\kappa a$, where v is the velocity of light.

Another way of putting it is to say that if a mass of this amount were moving with the speed of light, its kinetic energy would be half as great again as the potential energy of the electric charge when

standing still; for $\frac{3}{4} m v^2 = \frac{1}{2} e \cdot \frac{e}{\kappa a} = \frac{1}{2} QV =$ potential energy.

Now any appreciable quantity of matter, even a milligramme, moving with the speed of light, has a prodigious amount of energy; namely, for the mass of one milligramme, fifteen million foot-tons. Or as Sir William Crookes has expressed it: a gramme, or fifteen grains, of matter, moving with the speed of light, would have energy enough to lift the British Navy to the top of Ben Nevis.

Consequently the inertia of any ordinary quantity of electric charge must be exceedingly minute. Notwithstanding this, it is quite doubtful whether or not there really exists any other kind of inertia. The question whether there does or not is at present, strictly speaking, an open one; though to my mind it is practically closed.

The only way of conferring upon a given electric charge any appreciable mass is to make its potential exceedingly high, that is to concentrate it on a very small sphere.

A coulomb at the potential of a volt has an electrostatic energy of half a Joule, that is $\frac{1}{2} \times 10^7$ ergs.

The mass equivalent to this would be

$$\frac{2}{3} \frac{10^7}{9 \times 10^{20}} = \frac{2}{27} \times 10^{-13} \text{ gramme} = 10^{-8} \text{ milligramme.}$$

Raise the potential to a million volts, and the mass equivalent to a coulomb at that potential would be the hundredth part of a milligramme: still barely appreciable therefore.

The charge on an atom as observed in electrolysis is known to be 10^{-10} electrostatic units. If this were distributed uniformly on a sphere the nominal size of an atom, viz., one 10^{-8} centimetre in radius, its potential would be one hundredth of an electrostatic unit, or about 3 volts. The energy of such a charge would be 10^{-12} erg, and the inertia of a body which would possess this energy if moving at the speed of light would be 10^{-33} gramme.

But this is incomparably smaller than the mass of a hydrogen atom, which is approximately 10^{-25} gramme. Consequently the ionic charge distributed uniformly over an atom would add no appreciable fraction to its apparent mass.

If, however, the atomic charge were concentrated into a sphere of dimension 10^{-13} centimetre, its potential would be 1000 electrostatic units or 300,000 volts, its energy would be 10^{-7} erg, and its inertia 10^{-28} gramme, or about $\frac{1}{1000}$ of the mass of a hydrogen atom.

All this is a preliminary statement of undeniable fact: that is to say of fact which follows from the received and established theory of Electricity, whether such things as electrons had ever been found to exist or not.

All that we have stated is true of an ordinary charge on any ordinary sphere which can be made to move by mechanical force applied to it.

It gives us the phenomena

of electrostatics when at rest,
of magnetism when in motion,
of radiation when started and stopped,

and it incidentally, by reason of the known laws of electromagnetic induction, exhibits a kind of imitation inertia, and in that way simulates the possession of the most fundamental property of matter.

I will add a few more closely connected assertions. Apply a sufficiently violent E.M.F. to a charged sphere, and the charge may be wrenched off it.

Insert an obstacle in the path of a violently moving charged sphere so as to stop it mechanically with *sufficient* suddenness, and again it is possible for the charge, or something like it, to be jerked off it and passed on. But to do this the speed of the sphere, as well as the suddenness of stoppage, must be excessive. Usually the charge is merely thrown into an oscillation, when the sphere is suddenly stopped; and it then emits a solitary wave or spherical shell of thickness equal to the diameter of the sphere: or greater than that diameter by the amount the sphere has moved during its retardation. When the acceleration is moderate, however, the radiation is less energetic and also less intense: less energetic because its power depends on the square of the acceleration, less intense because it is spread over a thicker ethereal shell. Röntgen rays are perceptible only when the speed was great and the stoppage so sudden that the wave or pulse shell is strong and thin.

The doctrine of the behaviour of a charged sphere in motion, and the calculation of the value of the quasi inertia of an electric charge, was begun by Professor J. J. Thomson in an epoch-making paper published in the *Philosophical Magazine* for April, 1881—one of the most remarkable physical memoirs of our time.

The stimulus to this investigation was supplied by those brilliant experiments of Crookes, published in the Philosophical Transactions for 1879, which were preceded by observations of Plucker and Hittorf, and followed by other observations by Goldstein and Puluj and others in 1880.

In 1891 Sir William Crookes was your President, and in his inaugural address expounded further some of these brilliant experimental investigations, to which Schuster and many others had contributed. It is not too much to say that up to the time of Crookes the phenomena of the vacuum tube were shrouded in darkness, notwithstanding much laborious and painstaking work done both in this country and on the Continent in connection with them; but that since the researches of Crookes in the seventies, the theoretical luminosity of the vacuum tube has steadily increased, until now, as Maxwell predicted, it is shedding light upon the whole domain of electrical science, and even upon the constitution of matter itself.

APPENDICES TO PART I.

APPENDIX A.

Calculation of the Inertia of an Electric Charge.

Let a spherical conductor of radius a carrying a charge of electricity e move forward with moderate speed u; meaning by moderate speed

anything distinctly less than the speed of light; it constitutes a current element of magnitude $e\,u$, and its circuit is closed by displacement currents in the surrounding dielectric; for its lines of force arise in the medium in front and subside in the medium behind, and so a displacement of electricity takes place from fore to aft to compensate the motion forward, and the lines of displacement are identical with the magnetic lines due to a short magnet. A charge may be said to travel carrying its electrostatic lines with it, or it may be said to be constantly generating a radial electrostatic field in front and destroying one behind. When an electric field thus moves partly laterally it generates a magnetic field—in the present instance in circular lines round the line of motion—for the moving charge is an element of a linear current.

The generation of these magnetic lines acts so as to oppose the current which produced them, but so long as they continue steady they exert no effect on it. When they subside, however, they tend to prolong the current which maintained them. Consequently, if the moving charge (or current) tries to stop, its retardation meets with obstruction; it is constrained to persist by the subsidence of the magnetic field which its motion excited and maintains. Its velocity is not resisted, there is nothing equivalent to friction, but its acceleration + or — is obstructed, an effect precisely analogous to inertia. If it is at rest it will need force to start it, and if it is in motion its motion will persist.

The charge acts, therefore, as if it had inertia, and we can proceed to calculate its amount.

While moving it is a current and will be surrounded by rings of magnetic force, whose intensity, at any point with polar co-ordinates $r\,\theta$ referred to the line of motion as axis and the moving charge as origin, will be the quite ordinary expression (with $e\,u$ for the current element instead of $C\,d\,s$)—

$$H = \frac{e\,u \sin\theta}{r^2}.$$

The ordinary expression for the electrostatic force at the same point is—

$$E = \frac{e}{K\,r^2};$$

and if the motion is slow this value will be preserved, but if it is rapid the electric field gets weaker along the axis and stronger equatorially, having been shown by Mr. Heaviside (*Philosophical Magazine*, April, 1889) to be given by the following expression—

$$E = \frac{e}{K\,r^2} \cdot \frac{1 - (u/v)^2}{\left\{1 - (u \sin\theta/v)^2\right\}^{\frac{3}{2}}},$$

where v is the velocity of light.

The strength of the magnetic field will be similarly modified in this case; but the simplest mode of stating it is to express it in terms of E, and to say that *always*—

$$H = K\,E\,u \sin\theta,$$

The rate of transmission of energy will be the vector product of E and H; and the whole magnetic energy, that is the whole energy due to the current, *i.e.*, due to the motion, will be obtained by integrating the ordinary expression $\mu H^2/8\pi$ all over space outside the charged sphere, viz., from a to ∞ all round. In the general case this expression is a little long, but in the most important case, when the speed of motion u is decidedly less than the speed of light v, it is quite simple, and the working may as well be given:

$$\left.\begin{array}{l}\text{Kinetic}\\ \text{energy}\end{array}\right\} = \int_a^\infty \frac{\mu H^2}{8\pi} d\,(\text{vol.}) = \frac{\mu e^2 u^2}{8\pi} \int_0^\pi \int_0^{2\pi} \int_a^\infty \frac{\sin^2\theta}{r^4} dr \,.\, r d\theta \,.\, r \sin\theta\, d\phi$$

$$= \frac{\mu e^2 u^2}{8} \int_0^{2\pi} \int_a^\infty \frac{\cos^2\theta - 1}{r^2} dr \,.\, d\cos\theta = \frac{\mu e^2 u^2}{3a}$$

Comparing this with mechanical kinetic energy $\frac{1}{2} m u^2$, we see that the charge on the sphere confers upon it additional kinetic energy, as if its mass were increased on account of the charge by the amount—

$$m = \frac{2\mu e^2}{3a},$$

which may also be written—

$$m = \frac{2}{3} \frac{\mu K \,.\, e^2}{Ka} = \frac{2}{3v^2} \,.\, e \,.\, \frac{e}{Ka} = \frac{2}{3v^2} \times \text{charge} \times \text{potential},$$

or—

$$\frac{3}{4} m v^2 = \text{the electrostatic energy of the charge.}$$

In other words, the mass equivalent to the charge is such that if it were a piece of matter with constant inertia travelling at the speed of light, its kinetic energy would be half as great again as the potential energy of the electric charge when standing still.

APPENDIX B.

The Electric Field due to a Moving Magnet.

If a short bar magnet or uniformly magnetised sphere (its moment M being the intensity of magnetisation × the volume of the sphere) moves along axially, that is in the direction of its magnetisation, with velocity

u, it generates circular lines of electric force all centred upon its axis, much as a moving charge generates circular lines of magnetic force. If there is a conducting path around any such circle, then the motion of a magnet along its axis will generate a current in it, but if there be no conductor the motion will only result in an electric displacement which subsides when the magnet stops.

The intensity of the magnetic field at any point along the axis is well known to be $2\,M/r^3$; at any point on its equatorial plane it is $-M/r^3$; and in any intermediate direction it is, as regards magnitude alone—

$$H = \frac{M}{r^3}\sqrt{\left(1 + 3\cos^2\theta\right)}.$$

All this holds for the moving as for the stationary magnet, provided its speed does not approach that of light.

The electric force at the same point is—

$$E = \frac{3}{2}\frac{M\,u}{r^3}\sin 2\,\theta$$

$$= 3\,H\,u\,\frac{\sin\theta}{\sqrt{(4 + \tan^2\theta)}}.$$

The electrostatic energy resulting will be the integral of $K\,E^2/8\,\pi$ everywhere outside the moving magnetised sphere of radius a, viz.—

$$\text{Energy} = \frac{K}{8\,\pi}\iiint\left(\frac{3\,M\,u}{r^3}\right)^2 \sin^2\theta\cos^2\theta\,d\,r\,.\,r\,d\,\theta\,.\,r\sin\theta\,d\,\phi$$

$$= \frac{K\,M^2\,u^2}{5\,a^3} = \frac{M^2}{5\,\mu\,a^3}\left(\frac{u}{v}\right)^2.$$

The displacement acts like an elastic strain set up in the dielectric, storing the above energy statically; and so long as the magnet continues moving steadily the electric displacement exerts no force upon it; but acceleration will be resisted. If the magnet begins to go faster it sets up more displacement, and the act of setting this up constitutes a transient current, which opposes the motion as long as the acceleration continues, but dies out the instant the motion becomes steady again.

Conversely if the motion of the magnet began to slacken, the electric strain would begin to subside, and its subsidence would constitute an inverse transient current which would assist the motion *i.e.*, oppose the slackening. In other words, the variations of the circular electric strain in the surrounding medium confer upon a moving magnet a spurious or apparent momentum, in addition to its real mechanical momentum; and thus the elastic strain itself may be said to represent a spurious or apparent inertia due to magnetisation, in addition to any real mechanical

inertia which the body holding the magnetism may itself possess. And the amount of this extra inertia is—

$$m = \frac{2}{5}\frac{K M^2}{a^3} = \frac{2}{5}\frac{M^2}{\mu a^3 v^2} = \frac{8}{15} \cdot \frac{\pi I M}{\mu v^2}$$

$$= \frac{2}{5} \frac{H_0 M}{v^2},$$

where I is the intensity of magnetisation, and H_0 the intensity of the field, inside the substance of a uniformly magnetised sphere of radius a and magnetic moment M.

The equivalent mass moving with the velocity of light would therefore have an energy equal to one-fifth of the potential energy of the magnetised sphere if it were held at right angles to a field of its own internal intensity.

This result may be applied, *mutatis mutandis*, to a moving molecule consisting of a pair of equal opposite electrons not in absolute coincidence.

PART II.

Discovery of the Atom of Electricity.

Quoting again from the great Treatise of Clerk Maxwell, 1st Edition, we find on page 312, in the chapter on electrolysis, the following sentence :—

> "Suppose, however, that we leap over this difficulty by simply asserting the fact of the constant value of the molecular charge, and that we call this constant molecular charge, for convenience in description, one molecule of electricity."

Thus some idea of the conception of the atomic nature of electricity was forced upon men of genius by the facts of electrolysis and a knowledge of Faraday's laws. But Maxwell went on, after a few more paragraphs :—

> "It is extremely improbable that when we come to understand the true nature of electrolysis we shall retain in any form the theory of molecular charges, for then we shall have obtained a secure basis on which to form a true theory of electric currents, and so become independent of these provisional theories."

It is rash to predict what may ultimately happen, but the present state of electrical science seems hostile to this latter prediction of Maxwell. The theory of molecular charges looms bigger to-day, and has taken on a definiteness that would have surprised him.

The unit electric charge, the charge of a monad atom in electrolysis, whatever else it is, is a natural unit of electricity, of which we can

have multiples, but of which, so far as we know at present, it is impossible to have fractions.

I will extract the following sentence from Section 32 of *Modern Views of Electricity* :—

> "This quantity, the charge of one monad atom, constitutes the smallest known portion of electricity, and is a real natural unit. Obviously this is a most vital fact. This unit, below which nothing is known, has even been styled an 'atom of electricity,' and perhaps the phrase may have some meaning. . . . This natural unit of electricity is exceedingly small, being about the hundred-thousand-millionth part of the ordinary electrostatic unit, or less than the hundred-trillionth of a coulomb."

The atom with its charge is called an ion. The charge considered alone, without its atom, was called by Dr. Johnstone Stoney an electron or natural electrical unit.

What we learn with great accuracy from electrolysis is the ratio of the charge to the mass of substance with which it is associated. It matters nothing how much substance is chosen, whether 100 atoms or one, whether an atom or a gramme or a ton, the amount of electricity associated with it in electrolysis and liberated when the substance is decomposed, increases in the same proportion; the ratio is constant, and if determined for one substance is known for all.

This is the ratio which is technically known as the "electrochemical equivalent" of the substance. In the light of Faraday's laws, if this quantity is measured for one substance it is known for all, because the charge is the same for every kind of atom up to a simple multiple; and hence in specifying electrochemical equivalents there is nothing to consider but the atomic weight or combining proportion of the substance. Thus the electrochemical equivalent of oxygen is 8 times that of hydrogen, that of zinc is $32\frac{1}{2}$ times, and that of silver 108 times that of hydrogen. The substance chosen for a determination of the electrochemical equivalent may be the one which can be most accurately experimented on, and Lord Rayleigh has shown that such a substance is nitrate of silver, and has ascertained that if a current of one ampere is passed from a silver anode to a platinum cathode through a nitrate of silver solution, the cathode gains in weight by 4·025 grammes every hour. Hence the electrochemical equivalent of silver is

$$\frac{4{\cdot}025 \text{ grammes}}{1 \text{ ampere-hour}};$$

the electrochemical equivalent of hydrogen, being $\frac{1}{108}$ of this quantity, is—

$$\frac{4{\cdot}025 \text{ grammes}}{108 \text{ ampere-hours}} = \frac{4{\cdot}025}{108 \times 360} \text{ c.g.s.} = {\cdot}0001035 \text{ c.g.s.} = \frac{1}{96600} \text{ grammes per coulomb.}$$

Hence the ratio of an atom of electricity to an atom of hydrogen is 9,660 $\mu^{-\frac{1}{2}}$ c.g.s. units, or approximately $10^4 \sqrt{\left(\frac{\text{centimetres}}{\mu \text{ grammes}}\right)}$; the un-

known constant μ necessarily making its appearance because we are comparing quantities measured in different ways, viz., Electricity and Matter (see Appendix D).

The numerical part of this quantity is known with comparative exactitude,[1] that is to say up to the limits of error of experiment. To proceed further, we must make an estimate of the mass of an atom; that can be done, and has been done, in many ways, and we have been taught both by Dr. Johnstone Stoney and by Loschmidt, and notably by Lord Kelvin, that the mass of an atom of water is approximately 10^{-24} of a gramme, wherefore an atom of hydrogen will be approximately 10^{-25} gramme; whence the unit of electric charge is 10^{-21} c.g.s. magnetic unit, or 10^{-10} of an electrostatic unit or 10^{-20} of a coulomb.

I have emphasised this matter of the ratio m to e or e to m because it plays a considerable part in what follows. The absolute values are of less consequence to us than the ratio, and are only known approximately, but the ratio is known with fair accuracy, and the ratio for hydrogen is very nearly 10^4 magnetic units, or more exactly 9,660.

Thus what we learn from electrolytic conduction briefly summarised is that every atom carries a certain definite charge or electric unit, monads carrying one, diads two, triads three, but never a fraction; that in liquids these charges are definitely associated with the atoms, and can only be torn away from them at the electrodes; that the current consists of a procession of such charges travelling with the atoms; the atoms carrying the charges, or the charges dragging the atoms, according to from which point of view we please to regard the process.

Conduction in Gases.

We will now leave liquids and proceed to conduction by rarified gases, that is to say to the phenomena seen in vacuum tubes. If a long glass tube, say a yard long and two inches wide, with an electrode at each end, and full of common air, is connected to an induction coil and attached to an air-pump, the ordinary spark-gap of the coil being, say, two or three inches wide, we find that for some time after working the pump the electric discharge prefers the inch or two of ordinary air to a long journey through the partially rarified air in the tube, but that at a certain stage of exhaustion, one which any rough air-pump ought to reach, this preference ceases. A flickering light appears in the tube readily visible in the dark, which very soon takes on the appearance of red streamers like the Aurora Borealis, and then the sparks outside in the common air cease, showing that the rarified air is now the better conductor and the preferable alternative path. Let the exhaustion proceed further, and the axis of the tube becomes illumined with the glow, which is now much brighter, showing a band or thread of current, while the original spark-gap may be shortened down gradually to one-eighth of an inch, or even less, without any spark taking place

[1] The decimal places are correctly printed above; though the fact that 1 coulomb or 1 ampere-second is one-tenth of a c.g.s. unit, owing to the volt having been stupidly defined as 10^8 instead of 10^9, always stands ready to introduce confusion and error.

across it, showing that the rarified air is now a very good conductor When the best conducting stage is reached the tube is filled with a glow, called the positive column; and both ends of the tube are apt to look alike. If we exhaust still further—and to exhaust even as far as this something better than an ordinary air-pump is necessary, an oil or mercury pump being the most suitable—the column of light is seen to fill the whole tube, to gradually lose its bright red or crimson tint, and to break up into a number of very narrow discs like pennies seen edgeways. At the same time the spark-gap must be widened to something more like a quarter or half an inch to prevent the discharge from taking that path, and a dark space near the cathode now begins to be visible, the cathode itself being covered all over with a glow, while the anode is usually only illuminated at a point or two. The striæ into which the positive column has been broken up thicken and separate as exhaustion proceeds. The dark space near the cathode also enlarges, driving as it were the positive column before it into the anode, and looking as if it would presently fill the tube; but before it can do this it is noticed that the glow on the cathode itself is coming off as a kind of shell, leaving another dark space, a narrower and much darker space, inside it. The first dark space has been called Faraday's dark space; the second is generally known by the name of Crookes' This second dark space now increases in thickness, pushing the glow before it as the vacuum gets better and better; but the terminals of the spark-gap must now be pulled still further apart, else the discharge will prefer to take a reasonably long path through the air. Exhausting further still, the glow all disappears and the second dark space fills the whole of the tube; and now is noticed a new phenomenon, the sides of the glass have begun to glow with a phosphorescent light, the colour of the light depending on the kind of glass used, but generally in practice with a greenish light; a result evidently of being the boundary of the dark space. If exhaustion proceeds further, the resistance of the tube becomes very high, and the spark may prefer to burst through an equal and ultimately even a greater length of ordinary air. This is the condition of the tube so much investigated by Crookes, by Lenard and Röntgen, and by many other observers. It is the phenomena occurring in this dark space which have proved of the most intense interest.

Cathode Rays.

So far we have supposed that the cathode is a brass knob or other convenient terminal introduced into the tube; but if we now proceed to use other shapes, as Crookes did, using a flat disc or a curved saucer-shaped piece of metal, and if we then introduce into the dark space various substances, we shall find that the dark space is full of properties which are most clearly expressed by saying that it is a region of cathode rays—that is to say, of rays or something as it were shot off from the cathode. There is evidently something being thus shot off, which, however, is invisible until it strikes an obstacle, something which seems to fly in straight lines and to produce a perceptible effect only

when it is stopped. Such a something might be a bullet from a gun, which is quite invisible when looked at sideways, but may produce a flash of flame when it strikes a target, or may do other damage. So it is with these cathode rays: the region of their flight is the dark space; the boundaries of that space where the projectiles strike are illuminated. A substance with phosphorescent power, such as many minerals, or even glass, phosphoresces brightly, and the path of the rays can be traced by smearing a sheet of mica with some phosphorescent powder and placing it edgeways along their path. In this way it can be shown that they travel definitely in straight lines, not colliding against each other, but each shot as it were like bullets from an immense number of parallel guns. Where they strike the sides of the glass they make it phosphoresce; where they strike residual air in the tube, as they do if the exhaustion is not high enough, they make it phosphoresce also, and give, in fact, the ordinary glow surrounding the dark space.

These rays possess a considerable amount of energy, as can be shown by concentrating them by means of a curved saucer-shaped cathode and bringing them, as it were, to a focus. A piece of platinum put at that focus will (if the exhaustion is not too high) show evident signs of being red-hot—that is to say, will emit light. If the exhaustion is higher less heat is produced, though a phosphorescent light is emitted from suitable substances like alumina and most earths; but if the exhaustion is pressed further still the bombarded target emits no visible light but that higher kind of radiation known as Röntgen or X-rays. It may be doubted, however, whether the target itself emits these rays, whether its function is not rather to stop the projectiles as suddenly as possible by the massiveness of its atoms. Thus the best target would be a substance with the heaviest atoms. The X-rays are probably emitted by the suddenly stopped projectiles in a manner which has been investigated both by Sir G. Stokes and Professor J. J. Thomson, and which is intelligible to anyone who has studied the properties of moving electric charges moving at the speed of light: a matter on which Mr. Heaviside has written with extreme clearness in his volume called *Electromagnetic Theory*.

Cathode rays have a remarkable penetrating power; for Hertz found that a thin metal diaphragm, especially if it were of aluminium, was powerless to stop their passage completely; as could be demonstrated by the phosphorescence and other effects appearing in the further half of the tube beyond the diaphragm.

The position of the anode in such experiments is of small consequence. There must be one somewhere, and the easiest plan is to make it a cylinder through which the cathode ray bombardment goes. The bombarding particles fly in straight lines and decline to turn a corner, taking no apparent notice of the position of the anode, and exhausting themselves by bombarding the side of the glass opposed to them if the tube is bent into a V shape, for instance.

Lenard extended Hertz's discovery in a remarkable way by skilfully constructing a tube with its outer wall of very thin aluminium, so arranged as to be able to stand the atmospheric pressure outside. He then directed the cathode ray bombardment on to this window or

aluminium film, and showed that the rays can penetrate it and actually come outside into the ordinary atmosphere, where they are called Lenard rays, in honour of this indefatigable investigator, a friend and disciple of Hertz.

These Lenard rays make the air phosphoresce and produce the other effects which cathode rays can produce, but they are stopped within a moderate range by the immense obstruction they meet with from a substance of the density of ordinary air. Substances seem to stop them simply in proportion to the quantity of matter which they encounter, without regard to its nature. A thick layer of air would be about as opaque as a layer of water $\frac{1}{800}$ as thick; and even if the body put in their way is a solid, provided it is thin enough and not too massive, it will be penetrated by the rays; and phosphorescent effects will be produced on the other side of it. The rays can also affect photographic plates, and indeed do nearly all the things, though on a smaller scale and with much less penetrating power, that the later discovered Röntgen rays can do.

The Lenard rays are clearly cathode rays emerged from the tube, and it was the custom, at the date of their discovery, to think of them as flying charged particles of matter; though the extraordinary distance they could travel through common air, a distance comparable to an inch, was a manifest difficulty to such a hypothesis, seeing that things as big as atoms of matter cannot travel so much as $\frac{1}{1000}$ of an inch in ordinary air without many collisions.

Lenard accordingly adhered to the view that they were not material but ethereal; and although in the sense he probably intended this is not a tenable view, for they are not ethereal waves or anything of the nature of radiation, yet, as we shall see, neither are they ordinary material particles, any more than the cathode rays are. But that is just what we are now considering, and we will return to them as observed by Crookes in 1879.

Nature of the Cathode Rays.

We have seen that the impact of the cathode rays, speaking in language appropriate to the assumption that they are charged particles, will result partly in heat, or vibration of the impacted particles; partly in light or phosphorescence, due to the quiver of electrically charged atoms, or rather the electrical charges on atoms, as in the ordinary process of radiation; and partly in X-rays: all of which effects are readily seen at different stages of vacuum in a Crookes' tube. The *momentum* of the flying particles shot off from the cathode can also be exhibited by putting into their path some form of vane or little windmill, which will then be driven mechanically, as the vanes of a radiometer are driven by the recoil of the molecules of the residual air from the warmer surface, a stress being thus set up between the vanes and their glass enclosure. In the electric vacuum tube experiment the stress seems to be between the cathode or gun and the vanes or target, and the propelling force would appear to be the force of electrical repulsion, the particles travelling down the grade of potential just as they travel

in ordinary electrolysis; but whereas in ordinary electrolysis they meet with constant encounters and therefore progress very slowly, in the high vacuum they can fly for several inches in a free path without encountering anything, and therefore without causing any disturbance, giving rise to no appearance but that of the dark space. Phenomena occur only where they strike.

This was the view taken by the whole world of the nature of cathode rays after Crookes' demonstration; it was supposed that they were flying atoms, and that they were flying with ordinary molecular speed, but with a long free path—much longer than would have been expected from ordinary gaseous theory. The extraordinary length of free path was somewhat difficult to reconcile with the doctrine that they were flying atoms obedient to the ordinary laws of gases; except that, being subject to electrical propulsion all in the same direction, their course was more regular, and their encounters therefore fewer, than if they had been moving at random. This same feature of regularity it is that confers momentum upon them; their motion does not constitute heat, and is not to be considered as temperature; they are moving like a wind, rather than with the irregular unorganised motion appropriate, and solely appropriate, to the terms "heat" and "temperature," and to the ordinary kinetic theory of gases. Crookes indeed hazarded the surmise, by one of those flashes of intuition which are sometimes vouchsafed to a discoverer but are often jeered at by orthodox science at the time, that he had obtained matter in "a fourth state," and also that he had got in his tube something equivalent to what was contemplated in the "corpuscular" theory of light. There is something to be said for even this last mode of statement, when the particles are moving quickly enough; but how true the first was—that the matter in the dark space was in a fourth state, neither solid nor liquid nor gaseous—how true that was we shall presently see.

Meanwhile let us summarise the evidence for the view that the cathode rays are at any rate charged particles of some kind in extremely rapid motion. That they are in motion must be granted from the facts of their bombardment—driving mills, heating platinum, and the like; and in order to show that they are charged, the most direct plan is to catch them in a hollow vessel connected with an electroscope, as Perrin did; but another plan is to show that they have the properties of an electric current. If they are charged while in motion they constitute a current on Maxwell's theory, and therefore should be able either to deflect a magnet or to be deflected by it; and here comes one of the most simple and important experiments in physics at the present time. A definite form of old experiments by Goldstein and many other vacuum tube observers was arranged by Crookes in 1879, when he made the track of the rays visibly luminous by passing a selection of them through a slit and letting them graze along the surface of a film of mica covered with phosphorescent powder, and when he then brought near them a common horseshoe magnet. When this is done the track of the rays is at once seen to be curved; showing that it is not a beam of light we are looking at, but a torrent of charged particles behaving like an electric current and deflected by a magnet.

It is really the very same phenomenon as can be observed with difficulty when a current flows through metals, which was discovered by E. H. Hall, and known as the Hall effect.

The fact that the particles are thrown off the cathode, being evidently vigorously repelled by it, is sufficient to suggest that they must be negatively charged; the direction of the curvature caused by a magnetic field enables us to verify at once that the flying particles are negatively charged, and no comparable rush of positive particles in the opposite direction or in any direction has been observed. In that respect evidently the magnetic curvature of cathode rays in gases differs from the magnetic curvature of a current in metals, viz., that whereas in metals it is sometimes the negative and sometimes the positive current which is acted upon, according to the nature of the metal, and is always small, in gases it is the negative alone that appears to be acted upon and the action is always large. It seems, therefore, that for some reason or other the negatively charged bodies in a vacuum tube are much more mobile than the positive, and that the mobility of the negatively charged bodies is extreme. One striking method by which their mobility was displayed consisted in the observation by Professor Schuster that all parts of gas in a closed vessel became conducting when an electric discharge had taken place in one corner of it, so that even though the vessel consisted of different compartments, one compartment was made feebly conducting by a discharge in the other, provided that the two had any kind of gaseous communication, a fact which looked as if some extremely mobile particles, probably the negatively charged particles of cathode rays, could wander about to a considerable distance in a very short time and take their share in the conveyance of an electric current. The conductivity of gases appeared to be, indeed, entirely due to these loose or dissociated or detached charged particles, and where they were absent the gas did not conduct at all; it could be broken down, being a weak dielectric, by a sufficiently strong force, but it would not leak; whereas, when these loose charged particles were about, it leaked readily, becoming to all intents and purposes an electrolyte amenable to the feeblest electric influence. And the act of breaking down the air by an electric discharge was found to render the surrounding air for a time thus electrolytic. Its electrolytic quality, however, did not last long. The mobility of the particles which enabled them to travel to a considerable distance also enabled them to get rid of themselves by clinging to the sides of the vessel, or perhaps by re-uniting to some opposite but comparatively immobile positive charges, which after some time in their rapid journeys they must casually encounter. Mr. Townsend,[1] however, found that the conducting power lasted unexpectedly long if no dust was present: the dust particles evidently acting as intermedial receivers and storers of charge, promoting interchanges, which otherwise might be delayed from accidental non-collision. And the time that thus elapsed before the whole of the

[1] Mr. Townsend of Trinity College, Dublin, then working in the Cavendish Laboratory, Cambridge, now Waynflete Professor of Physics in the University of Oxford.

conductivity disappeared from dust-free air suggested that the moving particles must be very small, so that collisions were comparatively infrequent.

The mobility or diffusiveness of a gas depends on its mean free path, and that depends on its atomic size; the smaller it is, the more readily can it escape collision. Hence it is the collisions are so rare in astronomy: the bodies are small compared with the spaces between them. The behaviour of charged particles seemed to indicate that they must in some cases be something smaller than atoms. It seemed hardly likely that material atoms could behave in the way they did, so it was recollected that it had occurred to some philosophers, among them Dr. Johnstone Stoney, that electric charges really existed on an atom in concentrated form, acting as satellites to it; so on that view it was just possible that these flying particles might be not charged atoms at all, but charges without the atoms, the concentrated charges detached, knocked off as it were in the violence of the discharge and afterwards going about free; travelling at an immense pace because they would still be liable to the full electric force that they had experienced before, and yet would have shaken off the encumbrance of the material atom with which they had been associated. It is true that no such disembodied charges or electric ghosts had ever been observed. All the experiments that had been made in electrostatics had been made on charged matter, the surface or boundary of the matter acting as the locality for an electric charge. The facts of electrolysis had suggested or proved that the atoms themselves could carry charges, and hence that if a liquid were electrified, what was really happening was that a number of the atoms on its surface turned their similarly charged poles outwards; and the same might, for all we knew, be true for metals also, and thus every charge seemed associated with matter.

Yet at the same time the occurrences at an electrode, where an ion gave up its charge and escaped without it, indicated the *possibility* that perhaps the electric charge could exist alone, at any rate that it could be handed from one atom to another, and thus might conceivably exist alone for an instant. During this momentary isolation some might, in the freedom of a rarefied gas discharge, possibly escape, and wander about free.

To such hypothetical isolated charges, the unit charge or charge of a monad atom, the name "*electron*" has been given, and when I speak of an "electron" I mean to signify the at present purely hypothetical isolated electric charge. Whereas by the term "ion" I always signify the atom and its charge together.

Now if the flying particles which constitute the cathode rays were electrons rather than ions, if they were detached charges, leaving the atoms behind them (probably leaving the atoms from which they were detached positively charged), their extreme mobility and diffusiveness and high speed would be perfectly natural; and although they would not be matter in the ordinary sense, yet no difficulty need be felt at their possessing some of the properties of matter, at any rate such properties as appertain to matter by reason of its having inertia,

because, as we have seen, an electric charge itself does possess a certain kind of imitation inertia. Hence these electrons in movement would possess momentum, and might therefore propel windmills; they would possess kinetic energy, and therefore might heat a piece of platinum; and if suddenly stopped by a massive target when travelling at a high speed they might readily give rise to phosphorescent appearances, and even to the sudden pulse of radiation known as X-rays. But the existence of this last property ought to be capable of clear deduction on electrical principles if the matter is further gone into.

Increase of Inertia Due to Very Rapid Motion.

But now arises the question whether the distribution of charge on a charged body, together with its lines of force, will remain constant and unaltered while the body is rapidly moving; because if the distribution of lines of force is altered, then perhaps the inertia due to their lateral motion may be altered too.

Thus, for instance, imagine that the lines of force of a body in motion became more concentrated towards the axis or line of motion; the effect would be at once to diminish the lateral component of their motion, therefore to diminish the magnetic force which that lateral component causes, and thus to diminish the apparent or electromagnetic inertia of the moving charge.

On the other hand, if the lines opened out and became concentrated towards the equator, or plane normal to the line of movement, then a greater component of their motion would be of a kind suitable to excite a magnetic field; moreover, since both the fields would by this concentration increase in intensity, the whole transmission of energy (V EH) would be greater, and the inertia would apparently increase.

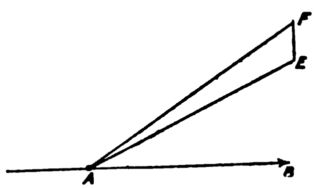
Thus, then, it may be possible that electric inertia may depend in some fashion on speed, a thing unknown in ordinary mechanics. I do not say that such dependence must be *untrue* in ordinary mechanics; on the contrary, I feel reasonably sanguine that it will be found true for matter moving sufficiently fast, and that it may even have a practical influence on some exceptionally rapid movements in astronomy. But however this may be, there is no doubt that theory points to an increase of electromagnetic inertia at excessively high speeds, and Mr. Heaviside has calculated its amount.

It will be observed that when a charge moves, it generates circular magnetic lines of force. Now these magnetic lines are not stationary, but are themselves moving at the same rate as the body, hence they generate fresh electrostatic lines, *i.e.*, cause an electric displacement away from the axis, which displacement is superposed upon the original radial displacement (away from or toward the centre) due to the charge.

At ordinary, at even violent speeds, this second order electric effect is insignificant, but it is there all the time, and must not be ignored when the speed becomes extravagantly high. It rapidly rises into prominence when the speed approaches the velocity of light, but at any speed much smaller than this such a second order effect is vanishingly small.

Its effect will be, as the above figure shows, to alter the distribution of the charge, making it move away from the poles and concentrate towards the equator of the charged sphere, when the speed is very great; ultimately becoming wholly concentrated upon the equator, all the rest of the sphere being denuded, when the speed attains that of light. And the electric lines of force will then be opened out into a fan or equatorial plane, like the spokes of a wheel which is rushing furiously along an elongated axle, the circumference of the wheel representing the direction of the magnetic field.

The magnetic force due to motion can be shown to depend on the ratio of the speed of the motion to the velocity of light, u/v. The secondary electrostatic force due to the motion of this magnetic field likewise depends on the same ratio. Hence the second order disturbance of the original uniform electrostatic field will be of the order u^2/v^2; and whenever we can afford to neglect quantities of this order, the distribution and therefore the inertia of the moving charge continue practically constant.



A is the charge, A B its line of motion, and A E its electric force in a certain direction when stationary; E F is the magnetically induced electric component due to the motion, and A F is the resultant electric force which replaces the original force A E. The magnetic force, to the motion of which E F is due, is perpendicular to the paper, and is itself caused by the motion; hence E F is a small quantity of the second order, for speeds distinctly less than that of light.

But when its speed of motion begins to approach the velocity of light, say even no more than $\frac{1}{10}$th of that speed, then a perceptible disturbance is to be expected, and something like a 1 per cent. increase of inertia must occur.

The complete investigation makes the inertia infinite when the speed reaches that of light, but there is probably no need to press this to extremes, unless the charge were an absolute point: clearly, however, the inertia will then be very great, and possibly therefore it may always be impossible to make matter, or at least charged matter, move with a speed greater than that of light. There may be ways out of this, however, just as it is possible for a bullet to move through air with a velocity greater than that of sound. This is managed by the violent adiabatic condensation of the air in front of such a bullet, the effect being to raise the appropriate velocity of sound to the required value.

If there is any way out of it in the case of the ether, however, it is not likely to be *this* way.

It has been shown both by Mr. Heaviside and by Prof. J. J. Thomson that if the speed of motion *is* ever greater than that of light, the fan or radial plane of lines of force bends backwards and becomes a conical surface, gradually closing up as the speed increases: an effect singularly reminiscent of the conical pulse travelling with a sufficiently rapid bullet, and demonstrated in Mr. Boys' bullet photographs.

No known speed which can be conferred upon matter is sufficient to

bring this latter effect into prominence. The quickest available carriage is the earth in its journey round the sun, 19 miles a second, or 60 times faster than a cannon-ball; but the earth's velocity is only the $\frac{1}{10000}$ of the speed of light, and consequently any spurious inertia due to its orbital motion is only 1 part in a hundred million; and even the accuracy of astronomy could not display any effect of that order of magnitude.

There are stars which move 200 miles a second, but even these have only one-tenth per cent. of the speed of light, and the excess inertia will be only 1 part in a million. The only known place where charges or charged matter move at speeds greater than this is in a vacuum tube. There the cathode-propelled particles are flying 20,000 miles a second or $\frac{1}{10}$th the speed of light, and they may have 1 per cent. excess inertia; or more if they can be persuaded to go still faster.

The substance of the above digression on the effect of rapid motion was written in connection with the Liverpool meeting of the British Association in 1896, and was communicated orally and very briefly to Section A in a discussion on the mechanism of the production of X-rays; for I then thought that unless great speeds, sufficient to disturb the static field, were reached by the cathode particles, they would not serve as efficient producers of the rays when suddenly stopped; but the matter has been gone into more fully now, and not only Mr. Heaviside's vol. 1 of *Electromagnetic Theory*, p. 57, may be referred to, where the circumstances of sudden stoppage of a charged body moving with the speed of light are illustrated, but also a paper by J. J. Thomson in the *Philosophical Magazine* for February 1898, dealing powerfully with the more general problem.

APPENDICES TO PART II.

APPENDIX C.

ON ELECTRICITY AND GRAVITATION.

Referring back to an article of mine in the *Philosophical Magazine* for November, 1882, page 358, we find the fundamental and necessary relation between constants stated thus, where M shall stand for magnetic pole and γ for Cavendish's gravitation constant—

$$e^2/K \equiv M^2/\mu \equiv \gamma m^2 = F l^2,$$

F being force and l being length.

If it is now going to turn out that a mass is composed of electric charges, it might seem as if e and m were quantities of the same nature, and were only numerically connected, whence it would follow that K and γ were of similar kind; in other words, Faraday's dielectric constant would become closely related to Cavendish's gravitation constant, and *weight* as well as *mass* would be traced to electricity; but such a deduction is unwarranted, there is nothing to prevent essentially

different properties of the ether being involved in the two kinds of force—gravitative and electric.

As to the nature of the gravitation constant itself we have—

$$\gamma = \frac{F\,l^2}{m^2} = \frac{l^3}{m\,t^2} = \frac{v^2}{m/l} = \frac{\text{sq. of velocity}}{\text{linear density}} = \frac{\text{energy/mass}}{\text{mass/length}}.$$

It is clear that if gravitation is in any sense of electric origin it must be a second order disturbance superposed upon the main electric effect, and be independent of sign. It would, in fact, depend upon e^4. For the gravitative force between two electrons at distance r would be—

$$F_1 = \gamma\frac{m^2}{r^2} = \frac{\gamma}{r^2}\left(\frac{2\,\mu\,e^2}{3\,a}\right)^2.$$

The electric force between the same two electrons at the same distance is—

$$F_2 = \frac{e^2}{K\,r^2}.$$

Therefore the ratio of the gravitative to the electric force at any distance is constant and equal to—

$$\frac{F_1}{F_2} = \frac{4\,\mu^2\,K\,\gamma}{9\,a^2}\,e^2 = \frac{4\,\mu\,\gamma\,e^2}{9\,a^2\,v^2} = \frac{2\,\gamma}{v^4}\,.\,F_0$$

where F_0 is the electric force between electrons in contact, and v is the velocity of light.

Numerically this ratio of the two forces is—

$$\frac{F_1}{F_2} = K\,\gamma\left(\frac{m}{e}\right)^2 = \frac{1}{9\times 10^{20}\times 1{\cdot}5\times 10^7}\left(\frac{1}{10^7}\right)^2 = 10^{-42},$$

so the electric force exceeds the gravitative as much as the globe of the earth exceeds in bulk an ultra-microscopic object.

When there is an agglomeration of electrons of opposite sign their electric influence at a distance disappears, but their gravitative influences are simply added. So with 10^{21} mixed electrons in each of two bodies at any distance apart, the gravitative force between them will equal the electric force between two single electrons at the same distance.

In my 1885 Report to the British Association on Electrolysis, page 745, the following statement is made:—If the opposite electricities were extracted from a milligramme of water and given to two spheres one mile apart, those two spheres would attract each other with a force equal to the weight of 12 tons.

APPENDIX D.

DIMENSIONS OF *e/m* RATIO.

The reciprocal of the electrochemical equivalent of a substance e/m may be expressed as regards dimensions in several ways, one of which

exhibits it as a certain large numerical multiple of $\sqrt{(K\gamma)}$, the geometric mean beween Faraday's dielectric constant and Cavendish's gravitation constant. For hydrogen, this numerical multiple is of the order 10^{18}; for silver 10^{16}.

Another way is obtained by writing—

$$e^2 = K F l^2 = \frac{m\,l}{\mu},$$

whence it follows that—

$$\frac{m}{e} = \frac{\mu\,e}{l} = \sqrt{\left(\frac{\mu\,m}{l}\right)},$$

and so e/m can be expressed in $\sqrt{\left(\frac{\text{centimetres}}{\mu\ \text{grammes}}\right)}$.

The artificiality of these dimensions is due to the fact that e and m have been conventionally measured in different ways; m is measured by ratio of applied external force to acceleration, while e is measured by repulsive force self-exerted on a similar charge at given distance.

If we express μ as a density (see "Modern Views of Electricity," Appendix p), the electrochemical equivalent comes out as expressible in grammes per square centimetre, that is to say a surface density.

It is noteworthy that while $\sqrt{(K\mu)}$ is of the same dimensions as $1/v$, $\sqrt{(K\gamma)}$ corresponds to $1/\epsilon$, where ϵ is an electrochemical equivalent.

PART III.

Determination of Speed and Electrochemical Equivalent of Cathode Rays.

The curvature of path produced in cathode rays by a transverse magnetic field, or the amount of rotation produced by a longitudinal magnetic field, constitutes an evident mode of attacking the problem of estimating their velocity.

If the velocity is constant and the magnetic field uniform, the curve into which the beam is bent will be a circle, and its course can be readily traced either directly, after Crookes' manner, by letting it graze a phosphorescent substance, or indirectly by inference from the position of a linear target placed so as to catch the deflected rays.

Consequently there will be no difficulty in determining the radius of curvature r; and the theory is the simplest possible, nothing more than stating that the magnetic force H, acting on the current element $e\,u$, is the necessary deflecting or centripetal force, $m\,u^2/r$, required to overcome the mechanical inertia of the particles; *i.e.*,

$$\frac{m\,u^2}{r} = \mu\,e\,u\,H,$$

whence $$\left(\frac{m}{e}\right) u = \mu\,H\,r;$$

or the ratio e/m is to the velocity of the particles as the curvature of their path is to the intensity of magnetic field which curves it.

The two factors on the right of this equation are directly measureable (μ being conventionally ignored as usual, or, what is a better mode of expressing it, measuring H as induction-density instead of as intensity of field), but the two factors on the left are both unknown, hence neither can be determined by this means alone: an assumption must be made about one or other of them, or else another independent kind of experiment must be made.

Assume, as many experimenters did, that u is a velocity appropriate to atoms flying in a gas of ordinary temperature, then the value of e/m comes out not so very far discrepant from the usual ionic value measured in liquid electrolysis, viz., 10^4 c.g.s. Or conversely, assume the usual ionic or electrolytic value for this ratio, and the cathode ray velocity comes out something quite appropriate to atoms of matter.

This, however, is a trap. These accidental coincidences may retard progress in a most serious manner, for they satisfy the mind and deter people from investigation. It is almost impossible to be completely on guard against them, and they are usually accepted until a more thorough qualitative acquaintance with the subject leads to an instinctive feeling that something is wrong somewhere.

So it was in this case, the long free path and the penetrating power of the cathode rays kept insisting that the particles were not really atoms of ordinary matter: a truth which both Lenard and Crookes had instinctively grasped, in spite of much criticism and valid arguments the other way; so in 1897 J. J. Thomson made a much more serious attack on the position.

He arranged that the magnet should deflect the rays into an insulated hollow vessel, connected with an electrometer and a known capacity, so that the aggregate charge of the cathode ray particles collected in a given time could be measured by the rise of potential observed. He also arranged that inside the hollow vessel they should fall upon a thermal junction of known heat capacity, connected by very thin wires to a galvanometer (acting therefore as a calorimeter), so as to measure their aggregate energy.

Thus he could make the following simultaneous determinations:—

$$N e = Q$$
$$N \tfrac{1}{2} m u^2 = W$$
$$\frac{m}{e} u = \mu H r$$

In these three equations there are four unknown quantities, but one pair can be treated as a ratio, and another, N, can be eliminated, and thus we get—

$$u = \frac{2W}{Q H r}$$

$$m/e = \frac{Q}{2W} \left(\mu H r \right)^2$$

When these brilliant measurements were actually made in the laboratory the atomic nature of cathode rays was, if not actually disproved, at all events rendered highly improbable; for their speed was found to be of the order ten thousand miles per second, or even as high as $\frac{1}{10}$ that of light in a favourable case, being always of the order 10^9 c.g.s., while the electrochemical equivalent was of the order 10^{-7} c.g.s., or about $\frac{1}{1000}$ that of hydrogen.

Changing the kind of residual gas in the tube, and changing the electrodes, made no difference to this last value. *The cathode rays were evidently independent of the nature of the matter present:* an exceedingly momentous fact. If they were matter at all, they appeared to be matter of some fundamental kind independent of the distinctions of ordinary chemistry. Their velocity, however, depended on the potential difference between the electrodes, in a way that suggested that they were really projectiles urged by the potential gradient acting along a given length of path. They were propelled by the cathode through an aperture in the anode, and the measurement of their speed was made in the tube beyond the anode, where they are travelling by their own momentum. The distance apart of anode and cathode did not, and on the projectile hypothesis ought not to, affect this speed; for though the potential gradient is steeper when anode and cathode are put close together, the length of path during which the particles are subject to it is diminished by a compensating amount, so that the velocity is theoretically independent of the distance between the electrodes, as long as the total difference of potential is maintained; it is the absolute difference of potential that determines the speed. But manifestly if the electrodes are too close together it may be difficult to secure a high difference of potential between anode and cathode, since they may spark into each other outside the tube; and if there is much residual gas in the tube it will likewise be difficult to maintain a high potential difference, because that residual gas, under the influence of the cathode rays, will conduct. Consequently the best speeds are obtained at high vacuum; and if the density of the residual gas inside the tube is constant, the speeds will be constant. The nature of the electrodes makes no difference, unless they give off gas or otherwise make it difficult to maintain the required potential difference.

Although the speed of the particles in cathode rays was thus found excessively great, their energy was only moderate, and their aggregate mass therefore excessively minute; their aggregate electric charge, however, was considerable. They were able to raise an electrical capacity of 1·5 microfarads several volts, sometimes as much as 20 volts, in the course of a second; and in the same time they might be able to raise a calorimeter, whose heat capacity was about 4 milligrams of water, by 2° C. Nevertheless their mass was so small that it would have taken one hundred years to collect a weighable amount, and then only about one-thirtieth part of a milligramme. They travelled with a velocity a hundred thousand times greater than the speed of rifle bullets, and represented the greatest velocity up to that time observed or even now known in matter, if matter they were; and the electrochemical equivalent, instead of coming out in accordance with that

observed in liquids, came out some thousand times smaller; that is to say, the charge associated with each particle of the cathode rays seemed a thousand times greater in proportion to the mass than the charge associated with an electrolytic ion, even of hydrogen.

If the flying particles were really atoms, there was no escape from the certainty that they were extraordinarily highly charged atoms; but if, as seemed more likely to the instinct of most of those who worked at the subject, the charge on the flying particles was the same as the charge possessed by an atom in electrolysis, then, assuming that the experiments were correct and correctly interpreted, there would be no escape from the conclusion that the mass associated with the ionic charge in cathode rays must be a thousand times smaller than the mass of a hydrogen atom; in which case the cathode projectiles might conceivably be the detached and hitherto hypothetical individual electrons or atoms of electricity themselves. It would be extremely rash, however, to jump to such a far-reaching conclusion on such comparatively scant evidence. The evidence must be confirmed by other departments of Physics or by other determinations based on a different method; and they must be further scrutinised in the light of the magnetised-radiation phenomenon observed by Professor Zeeman of Amsterdam. We will first describe a determination made by another method, and then some striking measurements applied to phenomena which belong apparently to other departments of Physics.

Further Measurements of Cathode Ray Velocity and *m/e* Ratio by Aid of Electrostatic Deflection.

Another and perhaps simpler method of determining the two quantities u and m/e was also employed by J. J. Thomson, viz., by deflecting the same rays both electrostatically and magnetically; by introducing a pair of supplementary electrodes, one above and one below the course of the rays inside the vacuum tube, and connecting them to the poles of a low potential battery, a few storage cells for instance, thus obtaining a vertical electrostatic field at right angles to the cathode rays. At the same time a magnetic field, produced by lateral magnet poles or by the lines of force due to an electric current in a circular ring, could be arranged at right angles to both the other directions; and thus the electrostatic deflection could be compared with, or used to neutralise, the magnetic deflection.

Let the cathode rays be received upon a needle-point covered with phosphorescent material and movable up and down in a measured manner; then the deflection of the rays can be observed by reading how much the needle has to be moved in order to catch a narrow beam which has travelled through a length l of either an electric field of strength E, or a magnetic field of strength H.

If u is the original velocity of the ray particles, travelling at right angles to both the deflecting fields, either of them will have a time l/u in which to act; and in that time an extra component w will be caused in the direction of the electric force, or perpendicular to the direction of the magnetic force, such that the rate of chango of momentum of

each particle will be $\frac{m\,w}{l/u} = \mathrm{E}\,e$ in the one case, and $= \mu\,\mathrm{H}\,e\,u$ in the other; wherefore the deflection will be—

$$\theta = \frac{w}{u} = \frac{e}{m} \cdot \frac{\mathrm{E}\,l}{u^2} \text{ in the one case,}$$

$$\text{and } = \frac{e}{m}\,\frac{\mu\,\mathrm{H}\,l}{u} \text{ in the other.}$$

Hence if in the actual experiments the two kinds of deflection be made *equal,* by adjusting the relative proportion of the two fields, we get simply—

$$u = \frac{\mathrm{E}}{\mu\,\mathrm{H}}$$

$$\text{and } \frac{m}{e} = \frac{l\,\mu^2\,\mathrm{H}^2}{\theta\,\mathrm{E}}.$$

This method, when applicable, appears to give fairly accurate results; and the outcome of the measurements is that when H or CO_2 or Air is in the tube—

$$u = 2 \text{ or } 3 \times 10^9 \text{ centimetres per second,}$$

$$\text{and } \frac{m}{e} = \text{from } 1{\cdot}1 \text{ to } 1{\cdot}5 \times 10^{-7} \text{ c.g.s. units.}$$

The chief difficulty about this mode of experimenting is caused by the fact that the ionisation of residual air in the tube causes it to become a temporary conductor, and so to screen the flying particles from most of the electrical influence. There is no guarantee that they feel the full effect of the electric field which is ostensibly being applied; indeed it is not easy to let them feel any of the effect. It used to be thought that they were not susceptible to electrostatic action at all, and this was often adduced as an obvious argument against their being electrically charged particles; but fortunately Thomson soon surmised the cause of this masking of the simple effect to be expected, and succeeded in showing that with high enough vacua and other precautions the screening ionised atmosphere could be removed, and the electrostatic deflection metrically observed.

Determination of Electrochemical Equivalent in the Case of Electric Leakage in Ultra Violet Light.

The same ratio of $m:e$, or a ratio of quite comparable magnitude, is obtained from phenomena which at first sight appear to be distinct.

One of these phenomena is the effect of ultra-violet light in discharging negative electricity from a clean metal or other surface; a phenomenon the investigation of which was begun by Hertz, and continued especially by Righi and by Elster and Geitel. (See one of the appendices to my "Signalling without Wires," published by the Electrician Co.) If ultra-violet light, whether from a spark or from a flame, fall upon a negatively electrified surface, then in general there will be a leak of electricity from that surface, which electricity can be received by any body placed opposite the illuminated one, and can be

used to charge an electrometer of known capacity, and so be measured. The writer has made very many experiments in this subject, which, however, have not yet been published. Now Elster and Geitel made the notable discovery that the introduction of a magnet affected the rate of leak, according to the direction of its lines of force. This phenomenon suggested a magnetic deflection of the lines of leak, which were shown by Righi to be singularly definite trajectories, and indicated that the leakage was due to the bodily propulsion of negatively electrified particles analogous to the cathode rays. A vacuum is not necessary to observe the effect, but in a vacuum the effect is more prominent and more accurately measurable. The difference between this case and an ordinary vacuum tube case is that there is no great E.M.F. or gradient of potential applied, there is accordingly nothing of the nature of a disruptive discharge ; and in fact there is no leak at all until by the stimulus of the presumably synchronous vibrations of ultra-violet light the molecules are thrown into a state of agitation, and the attachment of the negative charge, or of some negatively charged corpuscles, thereby loosened.

Two things are necessary to get the particles away from the plate ; they must be loosened by the impact of ultra-violet light—the direction of polarisation of this light having a very decided influence,—and the surface to which they cling must likewise be negatively charged, so as to repel them. Neither light alone nor electrification alone will produce the effect ; co-operation is necessary.

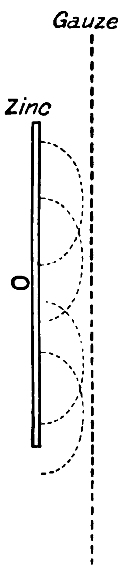


FIG. 1.

J. J. Thomson devised a most ingenious method of carrying out this experiment in a metrical manner, and of deducing from it the electrochemical equivalent of the charged particles, that is to say the amount of matter which each contained compared with the electric charge which each carried. To this end he employed the usual arrangement of a small negatively charged zinc plate on which ultra-violet light from a distant arc-lamp could shine, through quartz, and also through a parallel piece of wire gauze connected with an electrometer. The distance between the zinc plate and the metallic gauze was variable, and the experiment consisted in observing how much electricity reached the gauze from the negatively charged plate, under the influence of light, first without, and then with, a magnetic field of measured strength applied crossways to the region between them.

A little calculation of extreme beauty showed him that the paths of the flying particles under magnetic influence would be *cycloids*, whose generating circles contained the ratio m/e as well as the ratio E/H^2 ; that is to say their trajectory, if it could be observed, would involve the electrochemical equivalent required and likewise the ratio of the electric to the magnetic field applied, as well as the absolute strength of the magnetic field.

The calculation is so simple that it may be given here :—

Let the figure show the zinc and the gauze facing each other, close together, with a gradient of potential $(V-V^1)/d = E$ between them ; and let a magnetic field of induction density H be applied normal to the paper.

Then the motion of a charged particle detached and propelled from the origin into the region between the plates, provided that the plates are in vacuum so that there is no resisting medium to interfere, will be—

$$\begin{cases} m\ddot{x} = E\,e - H\,e\,\dot{y} \\ m\ddot{y} = H\,e\,\dot{x} \end{cases}$$

the initial values of $x, y, \dot{x}$, and $\dot{y}$, being all zero.

The solution of these equations, under these initial conditions, is—

$$\begin{cases} x = a\,(1 - \cos b\,t) \\ y = a\,(b\,t - \sin b\,t) \end{cases}$$

$$\text{where} \quad a = \frac{E}{H^2}\frac{m}{e} \quad \text{and} \quad b = H\,.\,\frac{e}{m}\,;$$

and from these we see that, whereas x is oscillatory in accordance with a versine, ranging from 0 to $2a$ and back, y is both oscillatory and progressive, completing its period in a time $\frac{2\pi}{b}$, and increasing in every such period by the amount $2\pi a$. In other words, the equations represent a *cycloid* traced by the rim of a circle of radius a rolling on the zinc plate.

There is no known way of actually observing this quite invisible and purely theoretical trajectory ; but when it is perceived that in accordance with this theory all the particles moving between the plates will have similar paths, so far as they do not come near the edge of either plate—in which case they would not be propelled so far—it becomes plain that there should be a critical distance within which the gauze would receive and intercept *all* the particles, and beyond which not a single one would be able to reach it. In the figure the gauze is depicted as set just beyond the critical distance, so that it would receive no electricity, even though the ultra-violet light were fully shining ; but so that if either its distance from the zinc were diminished, or the electric field strengthened, or the magnetic field weakened, the gauze would at once come within range and receive a plentiful supply of charge from the hypothetical cycloidally-flying particles. And the critical distance at which this would happen—a thing easily experimentally observed—would be independent of the brightness of the ultra-violet light, and would be merely the diameter of the generating circle ; in other words, the critical distance between the plates, when effective transfer of charge occurred, should be $2a$, or $\frac{2mE}{eH^2}$; a quantity which by this ingenious means could be measured. Wherefore the ratio m/e for this case can be experimentally determined, if E and H are both known. The apparatus employed is shown in Fig. 2.

The sharpness of actual experimental observation of the critical distance was not found quite so great as this simple theory would

indicate, because of disturbing causes, one of which was the presence of some residual air, interfering with the perfectly free path of the moving bodies; nevertheless it was sharp enough for fair determination; and the result was again, in this case also, that the ratio e/m came out 10^7 c.g.s., or more exactly 7×10^6; corresponding closely with the values found by J. J. Thomson, confirmed subsequently both by Lenard and Kaufmann, for the cathode ray particles.

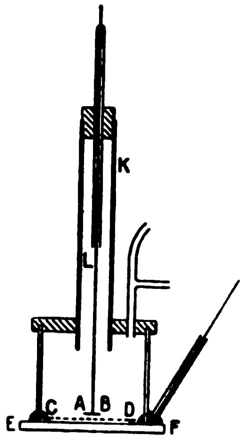


FIG. 2.—A B is the insulated zinc plate, C D is the gauze, E F is quartz; the source of ultra violet light is at some distance below, and the vessel can be filled with any gas and exhausted.

Another phenomenon on which measurements were made was the discharge of electricity from an incandescent carbon filament in an atmosphere of hydrogen. This also is subject to disturbance by a magnetic field, as was shown by Elster and Geitel; and a series of measurements, on lines similar to the preceding, resulted in a value—

$$\frac{e}{m} = 8{\cdot}7 \times 10^6 \text{ c.g.s.},$$

a value of the same order of magnitude as before, one thousand times greater than the electrochemical or electrolytic value for hydrogen, and many thousand times greater than for other substances, but always constant and independent of the nature of the substance present.

The only things which give the ordinary electrolytic value for this ratio are the *positive* carriers. These are not so easy to observe, but WIEN[1] has examined these by detecting and measuring the slight magnetic deflexion exhibited by certain rays behind the cathode in a vacuum tube, which Goldstein discovered and called *Kanal-strahlen*, and which Ewers proved were carriers of positive electricity. Wien has shown that they move slowly, and that in hydrogen their ratio e/m is of the order 10^4, that is to say the proper value for a hydrogen atom or ion; and with other substances the ratio has been found to vary with the substance and approximately to equal the electrolytic value, for these positively charged particles. J. J. Thomson has likewise made measurements on the positive carriers by means of the discharge from incandescent filaments and other positively charged hot bodies, and has confirmed Wien's results.

Thus it is forcibly suggested that whereas the positive carriers of electricity are *ions*, consisting of a unit + charge associated with an atom, the negative carriers appear to be dissociated from the main bulk of the atom, as if they were only fractions or fragments or constituents or appendages of an atom, which, detached and flying loose, are able to attain to prodigious speed; since any acceleration to which

[1] Wied. *Ann.* lxv. p. 440. See also Ewers in Wied. *Ann.* lxix. p. 187.

they are subjected is a thousand-fold greater than it is even for an atom of hydrogen, weighed down and burdened as that is with a mass of inert material and subject only to the very same propulsive force.

Think of the mobility of a set of particles which experienced the usual gravitation intensity g and had only $\frac{1}{1000}$ of the mass to carry. There is no known way of thus intensifying gravity—there are plenty of ways of diluting it, *e.g.* Atwood's machine, an inclined plane, etc., etc. But such a mobile particle as that we are now considering would drop under the influence of gravity not 16 feet in the first second, as everything we know does near the surface of the earth, but 16,000 feet, or about three miles; and would in one second acquire under gravity a velocity of six miles per second, enough almost to carry it out of the range of the earth's attraction altogether, and more than enough to carry it round the world.

The acceleration to which such particles are subject in a vacuum tube is far greater even than this, because there the forces are so prodigious; gravitation force on ions is almost infinitesimal compared with common electrical force on their charges. Suppose, for instance, that they are in a field such as easily occurs in a vacuum tube, of 3,000 volts per centimetre, one-tenth of what ordinary air will stand, or ten electrostatic units. The force urging one of these carriers to move is then $10 \times 10^{-10} = 10^{-9}$ dyne; the mass being moved, if it is a whole atom of hydrogen, *e.g.* if it were a positive carrier in a hydrogen atmosphere, is only 10^{-24} gramme, and accordingly the acceleration it experiences is 10^{15} centimetres per second per second, or a billion times g. Whereas if it were a negative carrier, in any atmosphere, its acceleration would be a thousand times greater still.

The velocity acquired in passing over a distance of five centimetres under this force is obtained by finding the square root of $2fh$; that is to say, it is 10^8 centimetres per second for a positive carrier, and 3×10^9 centimetres per second for a negative carrier; and these are approximately the orders of magnitude actually observed.

Thus the hypothesis becomes more and more justified that these units of electric charge can separately exist; perhaps carrying with them part of the atom, in which case they might be called corpuscles, having a material nucleus; perhaps pure disembodied electricity, whatever that may be—an electrical charge detached from matter,—in which case they would correspond with those hypothetical entities familiar in theoretical and mathematical treatment as "electrons."

APPENDIX TO PART III.

APPENDIX E.

Electric Saturation, etc.

In my Report on Electrolysis to the British Association for 1885 (see the Aberdeen volume, pp. 762, 763), I call attention to the possibility that an atomic theory of electricity would give rise to a maximum charge

possible on a given area. The maximum surface density would be attained when every atom was polarised so that its atomic charge faced outwards; and for a solid or liquid it would be very great. For the charge on each being 10^{-10} and the number of atoms per square centimetre being 10^{16}, it follows that the maximum surface density possible is $\sigma = 10^6$ electrostatic units per square centimetre. The corresponding gradient of potential would be $4\pi\sigma = 10^7$, or 3,000 megavolts per centimetre, and the corresponding tension would be $2\pi\sigma^2 = 6 \times 10^{12}$ c.g.s. $= 40{,}000$ tons to the square inch. Of course no dielectric would stand this pressure, but absolute vacuum might.

In practice, therefore, it follows that when a surface is charged highly, only an exceedingly small percentage of the molecules are polarised with their charges facing outwards. For instance, common air breaks down when the tension rises to a value $2\pi\sigma^2 = \frac{1}{2}$ gramme per square centimetre $= 400$ c.g.s.; wherefore the maximum σ in ordinary air is 8 electrostatic units per square centimetre; and this quantity would be afforded by the facing outwards of 10^{11} molecules, or one in every hundred thousand of a solid surface, or about a tenth per cent. of those in air.

It is shown on p. 760 of my 1885 B. A. Report on Electrolysis, that a potential gradient of the order 1 volt over molecular distance is sufficient to overcome atomic attraction and effect decomposition in liquids. Any liquid which is a conductor throws the whole applied stress on to a molecular layer contiguous to an electrode, and accordingly something of the order of a volt or two difference of potential between electrodes in such a liquid is required, and is sufficient, for decomposition.

PART IV.

The Electron Theory of Conduction and of Radiation.

Meanwhile the probability of the existence of electrons and the possibility of regarding them as the basis of all electric and of most other material phenomena, had seized hold of the imagination of several mathematical physicists, notably of Dr. J. Larmor and of Professor H. A. Lorentz. Both these philosophers endeavoured to trace all electric properties to the behaviour of electrons, usually of course in association with material atoms; and Dr. Larmor proceeded to try and invent a possible structure in the ether which should have the properties of an electron, whether positive or negative, and so reduce a great part of Physics to its simplest terms. This magnificent attempt at a new Principia has not yet been finally successful, but a great mass of very suggestive material is to be found in Dr. Larmor's contributions to the Transactions of the Royal Society, and in his recent great summary called "Ether and Matter"; which last, published by the Cambridge University Press as an Adams Prize Essay, is accessible, though barely intelligible, to all.

Suffice it here to say that the electron constitutes the basis of the

whole treatment, and that there is supposed to be no electric current except electrons in motion. They may move with the atoms, as in electrolysis; they may fly alone, as in gases; or they may be handed on from one fixed atom to the next, as in solids.

Conduction.

The possible modes of conduction or transmission of electricity are in fact three, which I may call respectively the bird-seed method, the bullet method, and the fire-bucket method.

The bird-seed method is adopted in liquids: it is exemplified in electrolysis; the bird carries the seed with it, and only drops it when it reaches an electrode.

The bullet method is the method in gases, as has been clearly realised by aid of the cathode rays: the space from cathode to anode represents the length between the breech and the muzzle of the gun, and the rest of the path is analogous to the trajectory of a bullet, which ultimately either penetrates or is stopped by a target, with a flash of light or other appropriate disturbance.

The fire-bucket method must be the method of conduction in solids, where the atoms are not susceptible of locomotion and can only pass electrons on from hand to hand; oscillating a little in one direction to receive them, and in another direction to deliver them up, and so getting thrown gradually into the state of vibration which we call heat. But it may be observed that this need for motion, in order to pass electrons on, becomes less and less according as the body is less subject to the irregular molecular disturbance we call heat. It may be the expansion and molecular separation, or it may be the irregular jostling and disturbance, that impede easy conduction; but certainly conduction improves as temperature falls, and transmission becomes quite easy at very low temperatures. The conduction of heterogeneous alloys is a less simple matter, being probably mixed up with back E.M.F. developed at innumerable junctions,—otherwise it would be instructive to examine the effect of low temperature on the conductivity of a metal which did not contract with cold. The extra conductivity of hot electrolytes is a totally different phenomenon: it is not true conduction, but convective locomotion of ions in their case.

Metals are bodies in which the transfer of an electron from one atom to another is easy, demanding no force as long as the process is not hurried—a process of the nature of a *diffusion*; insulators are bodies in which it can only be accomplished with violence. The transmission of vibrations along a chain of connected molecules may well occur through a not dissimilar kind of connection; and hence the conduction of electricity and the conduction of heat, though really different processes, may have many points in common.

Most is known about electrolytic and gaseous conduction. In gaseous conduction the negative electrons fly free and fast; the positive charges travel slowly by reason of their association with matter.

In liquid conduction both sets of electrons are associated with

atoms, and travel only as ions at a slow diffusion rate which was calculated by Kohlrausch, has been observed by myself and others, and is well known.

The rate of transmission in solids can only be inferred, and it would appear as if in one class of solids the positive were able to travel fastest, whereas in another class negative travelled fastest: a difference which is familiar in liquids. In acids, for instance, the positive charges travel much the quickest, because they are associated with light hydrogen atoms; and it is owing to the comparatively easy migration of this light or small hydrogen atom that acids are in general such good conductors.

The Hall magnetic bend, like Faraday's magnetic rotation, is a differential effect, and would be zero if positive and negative were equally acted on. In gases it is differential too, but there the negative charges are so free as compared with the positive, and fly so much more rapidly, that the Hall effect in gases, especially in rarified gases, is very great in comparison with the small residual effects found in liquids and solids.

Radiation.

But it is not only the progressive motion or locomotion of the electric atomic appendages that we have to consider; we must assume also that they are susceptible of motion in the atom itself, either vibrating like the bead of a kaleidophone, or revolving in a minute orbit like an atomic satellite. Indeed it is to the vibrations or revolutions of the electrons in an atom that its radiating power is due. Matter alone has no perceptible connection with the ether, a fact which is proved in my paper in the Philosophical Transactions for 1893 and 1897 [1]; it is electric charge which gives it any connection, and even then it has no *viscous* connection—there is no connection that depends upon velocity, or is of the nature of friction,[2]—it is purely accelerative connection; it is only when the charge vibrates, and during its accelerative periods, that it is able to influence the ether and carve it into waves [3]—waves consisting probably of alternations of shear, with no motion of the ether as a whole, but only a to-and-fro quiver of its equal opposite constituents over some excessively small amplitude: a kind of motion which constitutes what we know as radiation. It is not the atom pulsating as a whole which disturbs the ether, but the pulsations or vibrations, or the startings and stoppings and revolutions, of its electric charge. But normal or centripetal acceleration, involving nothing more than change of direction, is just as effective as actual change of speed. If an electric charge is able to describe a small orbit four-hundred-billion times a second, it will emit the lowest kind of visible red light. If it vibrates faster it will emit light of higher refrangibility; and the particular kind of radiation emitted by the atom of any substance, when in a fairly free state, will depend on the orbital period of its electrons: every frequency of vibration corresponding to a definite line in the spectrum.

[1] Lodge, *Phil. Trans.*, vol. 184, pp. 727–804, and vol. 189, pp. 149–166.
[2] See especially *Phil. Trans.*, vol. 189, p. 164.
[3] See Part I. of this paper, p. 49, also Appendix G.

But, if this be so, radiation must be susceptible to magnetic influence, for a revolving electric charge constitutes a circular current, and if a magnetic field is started into existence with its lines threading that circuit, it must, while it is changing in intensity, cause the speed either to increase or to decrease, and so will either raise or lower the refrangibility. If, then, electrons are revolving in every direction and a magnetic field is excited, during the rise of the field the pace of some will be increased and of some decreased, and this increase or decrease will not stop until the magnetic field is destroyed again.

Hence it would appear that if a source of radiation is put into a magnetic field, and its lines examined with a spectroscope, they should be doubled, some being raised in refrangibility, others lowered; or if any are left unaltered the line might be tripled, or if the motion was of a more complicated character the line might conceivably be quadrupled or sextupled, or any other change produced according to the character and complexity of the motion. At any rate it would seem that the line must be affected somehow, even if it were only broadened. It happened, however, that when Dr. Larmor theoretically perceived this, and did the calculation for it in 1895 to see how much effect might be expected, he made the natural assumption not that an electron could move by itself on a comparatively stationary atom, as above described, but that the atom was itself pulsating or revolving or quivering in some way as a whole and carrying its charge with it. On this assumption, knowing what he did about the massiveness of an atom, he perceived that the effect would be too small to see; and inasmuch as Faraday had, with imperfect appliances many years ago, looked for some such effect—not then guided by theory, but simply with the object of trying all manner of experiments—and had failed to see anything, no fresh experimental attempt to examine the question was initiated; nor was the matter publicly referred to until, as hinted above, Zeeman of Amsterdam, in 1897, with a powerful Rowland grating and a strong electromagnet, skilfully observed a minute effect consisting in a broadening of the lines emitted by a sodium flame placed between its poles; and then at once Dr. Larmor wrote to me, saying that this must be the effect which he had expected but thought must be too small to see. On receiving the intimation I immediately, with a little trouble, repeated and verified the experiment,[1] and exhibited it at the Royal Society soirée in May that same year.

From this simple but important beginning the large subject of the influence of a magnetic field on the radiation from different substances has been laboriously worked at; not only by the original discoverer, but by Preston in Dublin, Michelson in America, and others; and a whole series of important facts has been made out. Every line has been been studied separately; some lines are quadrupled, some tripled, some sextupled, and so on, as said above. One mercury line is resolved into as many as eleven components. The effect is therefore *not* too small to see, though it needs excessively high power and perfect appliances to see it; and so it became evident that if radiation were

[1] See *Proc. Roy. Soc.*, vol. 60, pp. 466, 513, and vol. 61, p. 413, or *Nature*, vol. 56, p. 237; also *The Electrician*, vol. 38.

due to moving electrons, their motion could not be handicapped by having very much matter associated and moving with them. It became possible, indeed, by making a measurement of the amount of doubling undergone by the lines in a given field, to ascertain how much matter was associated with the revolving electric charge in any given case; in other words, to make a determination of the electro-chemical equivalent effective in radiation, *i.e.*, of the ratio m/e. Indeed, Professor Zeeman, with considerable skill, made a rough determination of this kind at a very early stage, when he only saw the effect as a slight broadening of the sodium lines; and came to the conclusion that the electrochemical equivalent was quite different from that appropriate to electrolysis, being some thousand times smaller. He found, in fact, that the ratio e/m had in this case also the notable value already suspected in connection with cathode rays, viz., the value 10^7 c.g.s.

More recent measurements have confirmed this estimate, and shown that the ratio of charge to matter in the Zeeman case is practically identical with the ratio of charge to matter in the cathode ray case; in other words, that whatever is flying in the cathode rays is vibrating in a source of radiation, and that if the cathode rays consist of moving electrons, radiation is due to vibrating or revolving electrons.

Even this, however, does not constitute a proof of the existence of masses so much less than atoms; it may be only a remarkable coincidence. Besides, it is possible that in all these cases the whole atom is, after all, moving, but that its electric charge is one thousand times bigger than what had previously been observed as the proper charge of an atom.

But this assumption, improbable even for the cathode rays, becomes still more unlikely in the case of radiation, where it is not at all unnatural that only a very small part of the atom should be moving, the great bulk of it being practically stationary. Besides, the more the details of the Zeeman effect are studied, the clearer it becomes that the electron theory attributed to it from the first by Professor H. A. Lorentz, as well as by Fitzgerald and Larmor in England, is complete and satisfactory.

One of the earliest publications in England, both of the fact and of its elementary theory, is that given by the present writer in two articles in the *Electrician* for February and March, 1897,[1] which are worth referring to as representing incipient ideas on the subject before the full significance was grasped. The high value of the e/m ratio, viz., $\frac{1}{2} \times 10^7$ c.g.s., or fifty million coulombs per gramme, instead of the moderate electrolytic value, is spoken of on page 643 as a difficulty; and a Fitzgerald suggestion amounting virtually to the beginnings of an electron theory of the Zeeman effect is hinted at. Likewise an extremely short way of expressing the theory of the motion is given by the writer, in the following form:—

Consider the resolved part of any orbital motion projected on to a plane normal to the applied magnetic field H, and let the angular

[1] See Lodge, *Electrician*, vol. 38, pp. 568 and 643.

velocity at any point with radius of curvature r be ω, then the field will exert a radial component—

$$\pm \mu e \mathrm{H} r \omega$$

which will represent an increment or decrement of centripetal force

$$d(m r \omega^2),$$

whence it follows, to a first approximation, that—

$$d\omega = \pm \frac{\mu e \mathrm{H}}{2m},$$

and the change of frequency caused by the magnetisation will therefore be—

$$\pm \frac{\mu e \mathrm{H}}{4\pi m}.$$

The other component of the original orbit will manifestly be unchanged. This is far from being a complete and satisfactory theory, unless the projected motion happened to be circular ; but it was a brief and early attempt.

On the Electron Theory of the Magnetisation of Light.

Among the early contributions that have been made to the theory of moving charges, few are more remarkable than those of Dr. Johnstone Stoney in connection with the process of radiation, long before there had been any experimental verification of the separate existence of these electrons, or of the fact that the emission of light from a substance is due to their motion. Dr. Stoney had treated them in an astronomical manner, in 1891, dealing with an electron moving round an atom as if it were a satellite moving round a planet, and had discussed the various perturbations to which they might be subject, and the effect of those perturbations on the spectrum of the light emitted.

One of the simplest kinds of perturbation is what is called a progression or recession of the apses, being a slow revolution of the orbit in its own plane. Such a motion was shown to be able to account for a doublet in the spectrum; for of the two component vibrations into which the motion can be analysed, one has been made more rapid and therefore its light raised in refrangibility, the other has been made slower and therefore lowered in refrangibility.

Another closely allied kind of perturbation, analogous to precession of the equinoxes in the case of the earth, would result in a line triplet in the spectrum. This precessional motion occurs in an orbit subject to any oblique pull or deflecting force. Instead of yielding directly to that pull, its effect is to make the axis describe a kind of cone, the kind of motion that one sees in an inclined spinning-top : the pull of gravity on a spinning-top does not make it topple over, but makes it precess. So also with a hoop or bicycle when not vertical : instead of tumbling, it turns round and round in a circuit as long as its motion continues ; only falling when the motion ceases. Hence if the orbit of an electron were subjected to an oblique or deflecting force, the effect would be not to place it directly in the desired position perpendicular to a line of force,

but to cause it to precess; and this motion might be analysed into three, the acceleration and retardation of circular orbit above-mentioned, which would result in a doubling of the line, and a third component, viz. the one parallel to the axis, which would be unchanged, and would therefore represent a spectral line in its old position, the centre of the group of three. All this was clearly perceived by Larmor and Fitzgerald in connection with Dr. Zeeman's discovery, though they were anticipated by his great compatriot the eminent physicist, H. A. Lorentz; to whom the most complete publication of the theory is due, being in several respects anticipatory of the experimental results. For it may be observed that the light emitted by the oscillation components above spoken of will be all of one definite kind, due to vibrations in one definite direction and therefore polarised. The kind of polarisation would depend on the aspect from which it was seen. If seen at right angles to the axis of precession, all three lines should be plane polarised, the middle line at right angles to the other two. If, however, it be looked at along the axis of precession, then there should be no middle line, because the axial vibration would then be end on; and the two side lines should be circularly polarised.

Directly Zeeman had demonstrated the fact that a magnetic field applied to a source of light was able to act as a perceptible perturbing cause, Professor Lorentz was at once able to predict the whole of that which has been here stated about the tripling of the line seen sideways to the lines of force, and the doubling of the line seen endways, with all the polarisations as just stated; because the lines of magnetic force constitute the precessional axis. And all these effects were shortly afterwards seen by Zeeman and others, and are characteristic of the simplest circular orbit.

At first sight one might be inclined to suppose that the orbits would all face round and set themselves normal to the lines of force, like so many circular currents; but that is to forget the inertia of the travelling electron. It is manifest that since a revolving electron constitutes a circular current, its *tendency* will be to set itself with its plane normal to the lines of force; but since by hypothesis the revolving electron has inertia, the current will not so set itself, but will yield to the deflecting force in an indirect manner as a top does; or as the oblate spinning earth does—as explained by Newton in the Principia,—the axis of rotation having a conical motion round the lines of force, a motion which is called the precession of the equinoxes in the case of the earth, and the Zeeman effect in the case of a radiating atom.

This is an account of the chief part of the Zeeman effect, and may be regarded as the most fundamental kind of disturbance caused by a magnetic field on a source of radiation. But there may be other minor disturbances, just as in the case of the earth, whose axis is not only subject to precession, but also to nutation—a nodding movement superposed upon the main motion. It is also quite possible for the middle line, or for the two outer lines, or indeed for all three lines, to be doubled; thus giving rise not to the standard triplet, but to a quartet or a quintet or even a sextet,—appearances seen and photographed for some lines of some substances by Preston.

Even the two constituents of the double sodium line behave differently: one of the sodium lines, D_2, which had appeared only broadened to Zeeman at first, really becomes a sextet. The other sodium or D_1 line becomes a quartet; and a complete study of the behaviour under magnetism of all the lines and groups of lines given by different substances must result in a great extension of our knowledge in many directions; in fact it is hardly too much to say that the discovery of Zeeman, in the light of the theory of Lorentz, has doubled the power of spectrum analysis to throw light upon the processes of radiation and the properties of atoms, and has opened up a new department, as it were, of atomic astronomy, with atoms and electrons instead of planets and satellites.

APPENDICES TO PART IV.

APPENDIX F.

Size of Orbit of Radiating Electron.

Consider two electrons of opposite sign revolving round each other with luminous frequency n at any distance d; or better, consider a free negative electron revolving round a comparatively fixed equal positive charge attached to an atom, at distance d.

The force between them is $e^2/\mathrm{K}\,d^2$, so the acceleration is—

$$\frac{e^2}{\mathrm{K}\,d^2} \cdot \frac{3\,a}{2\,\mu\,e^2} = \frac{3\,a\,v^2}{2\,d^2}.$$

But the acceleration is also expressible as $4\,\pi^2\,n^2\,d$. Therefore—

$$d^3 = \frac{3\,a\,v^2}{8\,\pi^2\,n^2} = \frac{3\,a\,\lambda^2}{8\,\pi^2} = 3 \times \frac{10^{-13}}{80}\left(6 \times 10^{-5}\right)^2 = 10^{-23},$$

which is "Kepler's third law" for the case, and indicates that the distance at which luminous frequency is attainable is the atomic distance 10^{-8} centimetre; in other words, that the electron is roaming over the surface of the atom. If it got nearer to the centre of force than this it would have to revolve quicker; and such rapid oscillations may be excited among the internal paired electrons by shocks and collisions, or other perturbation.

The most important aspect of the above calculation is that it corresponds with the hypothesis that the whole of the mass of an electron is electric, and none of it material or unexplained; for it shows that a pure electron is able to revolve at distances of the molecular order with luminous frequency.[1] The square of the wave length emitted is proportionate to the cube of the radius vector; provided the plane of the orbit contains the centre of force. Otherwise there may be constrained motion of smaller amplitude, analogous to that of a conical pendulum.

[1] See Lodge in *The Electrician* for March 12th, 1897, vol. 38, p. 644.

APPENDIX G.

The Radiating Power of a Steadily Revolving Electron.

Consider an electron revolving as above (Appendix F) in an orbit of atomic dimensions d with luminous frequency n; and calculate its radiating power.

The fundamental expression for the amount of energy emitted per second as waves in the ether, by a moving charge e, was given by Larmor in *Phil. Mag.*, December, 1897, page 512, also in "Ether and Matter," page 227, namely—

$$\frac{2\,\mu\,e^2}{3\,v}\,\dot{u}^2,$$

where $\dot{u}$ is acceleration, and where $\mu\,e^2$ may be taken as 10^{-40} gramme-centimetre, according to most recent measurements. But in a circular orbit of radius d the acceleration is—

$$\dot{u} = \left(2\,\pi\,n\right)^2 d = 40\left(5 \times 10^{14}\right)^2 10^{-8} = 10^{23} \text{ c.g.s.};$$

therefore the radiating power of a single electron, so moving, is—

$$\frac{2\,\mu\,e^2}{3v}\,.\,d^2\left(2\,\pi\,n\right)^4 = \frac{2 \times 10^{-40}}{9 \times 10^{10}} \times 10^{46} = 2 \times 10^{-5} \text{ ergs per second.}$$

But the total available energy possessed by the revolving electron of linear dimensions a is only—

$$\frac{\mu\,e^2}{3\,a}\,u^2 = \frac{\mu\,e^2}{3\,a}\left(2\,\pi\,n\,d\right)^2,$$

namely its kinetic energy (for of course it cannot radiate away or dissipate its electrostatic energy), and this amounts to—

$$\frac{10^{-40}}{3 \times 10^{-13}}\left(2\,\pi \times 5 \times 10^{14} \times 10^{-8}\right)^2 = 3 \times 10^{-13} \text{ ergs},$$

its velocity being 3×10^7 centimetres per second, or one-thousandth that of light. So if the electron were isolated from any supply of energy, and if it could maintain the pace, it would at this rate radiate away all its kinetic energy in 10^{-8} of a second, that is to say in three or four million revolutions. This may seem a rapid rate of cooling, but it is not surprising for an isolated atom at a red heat.

We may express the ratio of the radiating power of a single electron to its total luminous energy, by the fraction—

$$\frac{2\,a}{v}\left(\frac{\dot{u}}{u}\right)^2 = \frac{2\,a}{v}\left(2\,\pi\,n\right)^2 = 8\,\pi^2\,n\,\frac{a}{\lambda} = 70 \text{ million per second.}$$

In any large assemblage of atoms the radiation is not free and unrestrained, nor is it unmaintained, like this; but it must always be considerable at anything like luminous frequency, and it is proportional

to the fourth power of the frequency. At a frequency which emits a wave ten times as long as a luminous wave the radiating power of a revolving electron is only one ten-thousandth of that above calculated, but even so it is significant; it must be remembered, however, that all substances are actually engaged in radiating energy, although at ordinary temperature there is usually absorption enough to compensate the loss.

The high speed of a revolving electron suggests, says Larmor, that it is apt to fly away tangentially with this sort of velocity when joggled off by any means; consequently he might attribute the high velocity of cathode ray particles to this cause rather than to propulsion by a gradient of potential. But it seems to me more likely that the orbital velocity is utilised only by those electrons which are flung off spontaneously from certain substances possessing one variety of radioactivity; whereas from charged surfaces, possessing a real propulsive force, electrons may be ejected so as to reach a speed higher than that, approximating more closely to the speed of light, a value which the rapid increase of inertia at such speeds would ensure that they should never actually attain.

APPENDIX H.

Faraday's Prophetic Nomenclature.

Students of the life of Faraday will remember that when he discovered the rotation of the plane of polarisation by a magnetic field applied to dense bodies in which light travelled along the lines of force, —wresting the secret from nature by strong and pertinacious experimental research that would not be denied, though the time was as yet by no means ripe for comprehension of the fact when it was discovered —he labelled his discovery in a fit of enthusiasm, "The Magnetisation of Light and the Illumination of Magnetic Lines of Force:" a label which puzzled contemporaries for a long time.

It is difficult to see what meaning he can have attached to these phrases; and for many years afterwards they appeared unsuitable misnomers, indicating a foggy conception of his own discovery.

It is not likely that his state of mind was really at all clear on the subject, and probably he would at a later stage have been willing to plead guilty to a less than lucid mode of conceiving the phenomenon; which nevertheless always specially pleased him, though when it was reduced to a mere rotation of the plane of polarisation, it seemed to many mathematicians and physicists to have lost its unique and surprising interest. It must always be remembered, however, that interest was never lost by either Lord Kelvin or Clerk Maxwell, and that it was the chief fact which incited Maxwell, many years later, to begin developing his electro-magnetic theory of light.

But how do the titles strike us now? Do they not indicate some extraordinary unconscious insight, such as is frequently experienced by a great discoverer in the enthusiasm of discovery? Remember that the Hall effect, the Zeeman effect, the Aurora Borealis, and Faraday's rotation are all closely connected, by means of the electron theory.

In the cathode ray tube the flying electrons are deflected by a cross magnetic field; or if they fly along the lines they are twisted into a spiral path round them. In the Aurora Borealis this effect is carried out in the upper region of the air on a gigantic scale, and the earth's magnetic "lines of force are illuminated" by flying electrons from the sun entangled and guided by them. In the Hall effect this same influence is felt by the slowly moving crowd of electrons as they are handed on from one atom to the next, causing a curvature of the current path, in which either positive or negative may predominate. In the Zeeman effect the same cause operates on the revolving and vibrating electrons associated with a radiating atom and constituting a source of light; wherefore we may truly say that the "light is magnetised," for the source of light is magnetised directly, and the effect is impressed on and retained by the light emitted, and is made visible by spectrum analysis.

The first intimation of that magnetic influence on light which lies at the base of all these at first sight apparently diverse phenomena was detected by Faraday in his slight differential rotation of the plane of polarisation in one direction or the other by a magnet, according as the positive or the negative electrons in the dense substance were most affected.

Hence the title which he affixed to his discovery: "The illumination of the lines of magnetic force and the magnetisation of light," may be regarded as a prophetic flash of genius.

A not altogether dissimilar flash has already been referred to, when Crookes hinted prematurely that in the cathode rays we had something like corpuscular light, and also like matter in a fourth state, neither solid, liquid, nor gaseous. For, whether quite right or not, he was far more right than the critics of those days who presumed to deride him.

PART V.

Determination of the Mass of an Electron.

So far, all the measurements quoted have resulted in a consensus of certainty respecting our knowledge of e/m for gaseous conduction and radiation; and the measurements made on the cathode rays in a Crookes's tube, or near a plate leaking in ultra-violet light, have likewise given us a knowledge of their velocity, and shown that it is about one-thirtieth of the velocity of light, more or less according to circumstances. But so far no direct estimate has been made of either e or m separately. The difficulty of making these measurements is great, because we are dealing with an aggregate of an enormous and unknown number of these bodies. It would not be difficult to make a determination of the aggregate mass of a set of projectiles, say N m, where N is the number falling on a target in a given time, by means of the heat which the blow generates; or better, perhaps, by the momentum which they would impart to a moving arm after the fashion of a ballistic pendulum; provided their velocity u were known as in this case it is. The

aggregate energy, $\frac{1}{2} N m u^2$, or the aggregate momentum, $N m u$, could thus be found; but how is m to be separated from N?

Again, if the particles are collected in a hollow vessel attached to an electrometer of known capacity, it is not difficult to estimate the total quantity of electricity which enters the vessel in a given time, that is to say, to determine $N e$; but, again, how are we to discriminate e from N?

We may consider the following quantities experimentally determined, by researches carried on at the Cavendish laboratory and elsewhere and so far already described or indicated :—

$$e/m$$
$$u$$
$$N e$$
$$N m$$

See above, Part III., for measurements of these quantities for the case of cathode rays.[1]

Another thing that is comparatively easy to determine, especially in such cases as leak from a negative surface under the action of ultra-violet light, or the conductivity of air induced by the impact of Röntgen rays, is the total current transmitted; viz. the quantity $N e u$ the quantity of electricity conveyed per second. Measurements of this quantity have been made not only by Lenard[2] and Righi[3] and Thomson,[4] but in various gases by Rutherford,[5] now Professor at Montreal; by Beattie[6] and de Smolan at Glasgow, by Zeleny[7] of Minnesota, by McClelland[8] on hot gases from flames, and by McLennan[9] of Toronto.

Professor Zeleny in particular measured the velocity by a safe and direct method of making the particles fly against a wind down a tube, and observing the rate of the current of air which was just able to withstand their progress: these measurements constituting a satisfactory confirmation of Thomson's and Rutherford's more indirectly inferred results.

If only it were now possible to *count* the corpuscles or electrons, to determine the number N which are started into existence, or which enter the hollow vessel, or which take part in conveying the current in the case of a leak by ultra-violet light, we should no longer have to *guess* at the actual value of e and of m separately, but should have really *determined* them.

This brilliant research has actually been carried out by Professor J. J. Thomson, by means of a method partly due to Mr. C. T. R. Wilson, supplementing a fact discovered by Mr. Aitken, and interpreted in the light of a hydrodynamic theorem arrived at long ago by Sir George Stokes.

I must be excused for waxing somewhat enthusiastic over this matter: it seems to me one of the most brilliant things that has

[1] J. J. Thomson, *Phil. Mag.*, October, 1897.
[2] *Wied. Ann.*, vol. 63, p. 253.
[3] *Rend. della R. Accad. dei Lincei*, May, 1896.
[4] *Phil. Mag.*, November, 1896. [5] *Ibid.*, November, 1896, and April, 1897.
[6] *Ibid.*, June, 1897. [7] *Ibid.*, July 1898. [8] *Ibid.*, July, 1898.
[9] *Phil. Trans.*, vol. 195, p. 49, 1899.

recently been done in experimental physics. Indeed I should not take much urging to cancel the "recently" from this sentence; save that it is never safe for a contemporary to usurp the function of a future historian of science, who can regard matters from a proper perspective.

The matter is rather long to explain from the beginning, and I must take it in sections.

Aitken and Cloud Nuclei.

First of all, Mr. John Aitken,[1] of Edinburgh, discovered in 1880 that cloud or mist globules could not form without solid nuclei, so that in perfectly clear and dust-free air aqueous vapour did not condense, and mist did not form. (See, for instance, my lecture to the British Association at Montreal, in 1884, on "Dust"—*Nature*, vol. 31, p. 268.)

Without solid surfaces, in clear space, vapours could become supersaturated; but the introduction of a nucleus would immediately start condensation, and according to the number of nuclei, or condensation centres, so will be the number of cloud globules formed.

Every cloud or mist globule is essentially a minute raindrop, not floating in the least, but falling through the air—falling slowly because it is of such insignificant weight and is moving in a resisting medium—but falling always relatively to the air. A cloud may readily be carried up by a current of air, but that is only because the air is moving up faster than the drops are trickling down through it. No motion of the air disturbs the relative falling motion: the absolute motion with reference to the earth's surface is the resultant of the two.

The fact that nuclei are required for mist precipitation can be proved by filtering them out with cotton wool, and finding that as the nuclei get fewer the mist condensation differs in character, becoming ultimately what is called a Scotch mist, such as forms in fairly clean air; where since the dust particles are comparatively few, the centres of condensation are few also, and accordingly each has to condense a considerable amount, so that the drops are bigger, and not nearly so close together; wherefore they fall quicker like very fine rain. In perfectly clean elaborately-filtered air the dew point may be passed without any vapour condensing, and the space will remain quite transparent in spite of its being supersaturated with vapour.

The reason for this effect of, and necessity for, nuclei, is well-known in the light of Lord Kelvin's theory concerning the effect of curvature on surface tension,[2] because the more a liquid surface is curved the more it tends to evaporate, and an infinitely convex surface would immediately flash off into vapour. Consequently an infinitesimal globule of liquid cannot exist; vapour can only condense on a surface of finite curvature, such as is afforded by a dust particle or other body consisting of a large aggregate of atoms. For it must be remembered that a single grain of lycopodium powder contains about a trillion atoms, and a dust particle big enough to condense vapour need not consist of

[1] *Trans. R.S. Edin.*, 1880.

[2] See, for instance, Maxwell's *Theory of Heat*, 1891 edition, p. 290.

more than a billion, or perhaps not more than a million, atoms, and need by no means be big enough to be visible. It is, however, material enough to be stopped by a properly packed cotton-wool filter.

J. J. Thomson and Electrical Nuclei.

In 1888 it was shown by J. J. Thomson, in his book *Applications of Dynamics to Physics and Chemistry*, p. 164, that electrification of a body would partially neutralise the effect of curvature, and so assist the condensation of vapour on a convex surface.

Consider a drop of liquid, or a soap bubble; the effect of the convexity of the surface is to give a radial component of surface tension inwards, causing an increased pressure internally. The effect of electrification is just the opposite: it causes a direct pressure outwards, which goes by the name of the electric tension.

The way these depend on size is as follows:—

The radial pressure component of the surface tension T is

$$\frac{2\,T}{r} \text{ inwards.}$$

The electric pressure or tension is

$$2\pi K \sigma^2 = \frac{e^2}{8\pi K r^4} \text{ outwards.}$$

They are differently affected, therefore, by the size of the globule; hence at some size or other they must balance, and such an electrified convex surface will behave as if it were unelectrified but flat. Accordingly vapour which would refuse to condense on an ordinary convex surface, until far below the dew point, will begin to condense on it, if sufficiently electrified, the instant the dew point is reached.

The critical size at which the ionic charge enables a sphere of water to act as regards condensation as if it were flat, can be reckoned by equating the pressure to the tension, thus:—

$$\frac{2\,T}{r} = \frac{e^2}{8\pi K r^4}$$

$$\text{or} \quad r^3 = \frac{e^2}{16\pi K T} = \frac{10^{-21}}{50 \times 80} = \frac{1}{4} \times 10^{-24} \text{ c.c.}$$

whence $r = 10^{-8}$ approximately, or is of atomic magnitude.

Hence *ions* can condense vapour; and anything smaller which possesses the same charge can condense it still more easily.

In moist air, therefore, it would appear (parenthetically) as if electrons could hardly exist isolated, but must be associated with at least an atomic mass of matter.

Accordingly an electric charge assists vapour to condense; and a sufficient electric charge might cause it to condense on quite a small body—as small even as an atom, or smaller. Hence in the presence

of electrified ions or electrons, dust particles are not necessary for condensation. Vapour may condense on these electrical nuclei without the need for solids of finite curvature. The electrical nuclei cannot be filtered out by cotton wool : they will exist or can be produced in dust-free air. No doubt if they are passed through a great amount of metal gauze they may be diminished in number, but they are not easy to get rid of except by their own diffusion, which does ultimately enable them to pair off or to migrate to the sides of the vessel. They can be got rid of, most easily, however, by electrolysing the air, that is to say by supplying electrodes maintained at a few volts difference of potential. They will then immediately make a procession, as in electrolysis, only with much greater speed, because their motion is much less resisted or interfered with by chance collisions; so they will soon reach and cling to their respective electrodes, and in that case again no true mist can form.

While ions or electrons are present in considerable numbers a thick mist will form whenever the space is saturated with vapour, but it will be a mist of different appearance from the slight rain-like condensation which may be seen forming round the few residual dust particles. The mist globules will usually be of uniform size, and some estimate of that size can be roughly attempted by the diffraction colours which can be seen if a point of light is looked at through the mist: not, however, a very easy plan of making a trustworthy estimate.[1]

Electrical nuclei can be produced in various ways—by anything, in fact, which dissociates the air or which fills it with ions. Some are produced by the splashing and spray of water, some are given off from flames, and from red-hot bodies, they are produced in considerable numbers when Röntgen rays travel through air, they can be given off by radio-active substances like uranium, and they are easily emitted by a negatively charged metallic surface exposed to ultra-violet light.

Wilson and Metrical Cloud Condensation.

Mr. C. T. R. Wilson,[2] in his study at the Cavendish Laboratory of cloud formation under the influence of Röntgen rays and by other methods, devised a plan for precipitating a definite and known quantity of aqueous vapour in a visible form. This was done by an arrangement for making a sudden or adiabatic expansion of saturated air, and making it to a carefully measured amount. The apparatus employed is shown in Figure 3.

One test-tube moving inside another is employed as a piston, and by a certain arrangement the piston was enabled to drop with great suddenness and thus to produce a measured small exhaustion in the reservoir containing the gas under experiment ; saturated as it is with vapour, and supplied with electric nuclei. The mist at once formed, and the drops began to fall slowly, as usual. Mr. Wilson tried to get an estimate of their size from the colours, but it was difficult and unsatisfactory. If the size had been known, their number would have

[1] See C. T. R. Wilson, *Phil. Trans.*, 1897, A, vol. 189, p. 283.
[2] *Phil. Trans.*, A, 1897, vol. 189, p. 265.

been known too, because the measured amount of expansion had produced a known fall of temperature below the dew point, and so had condensed a known amount of aqueous vapour, which would be distributed equally among all the equal globules.

It occurred to J. J. Thomson that a better estimate of size could be made by observing their rate of falling, which is a thing not difficult to observe since they all fall together, being all of the same size. In any mist formed in a bell-jar it is easy to watch it settling down, by watching its fairly definite upper surface, a clear space being left above it which gradually increases in thickness as the cloud falls. The

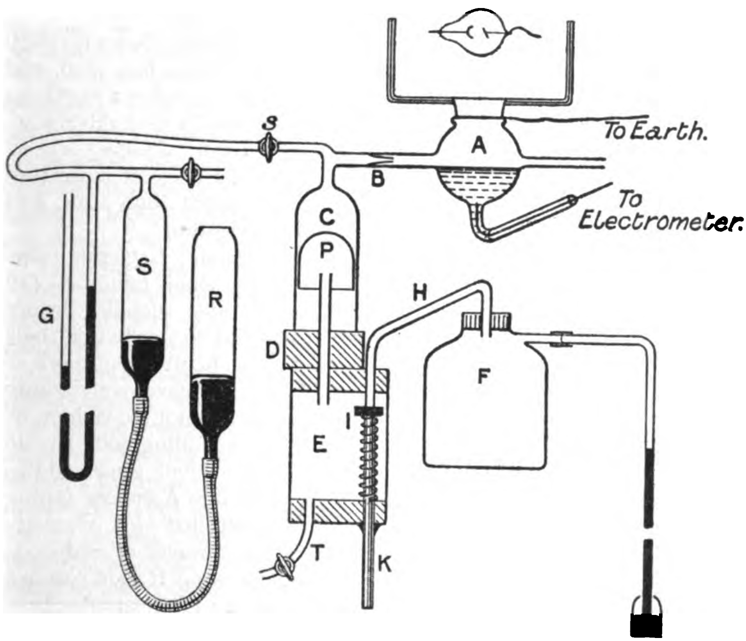


FIG. 3.—A is the vessel in which the fog is formed whose rate of fall is to be measured by Mr. Wilson's method as used by him for the ionisation produced by X-rays. The vessel A, containing some water, is in communication with a vessel C through the tube B. Inside C is a thin-walled test-tube P, which serves as a piston. D is an indiarubber stopper closing the end of tube C. A glass tube connects the inside of the test-tube P with a space E. This space may be put in connection with an exhausted space F through the tube H. The end of the tube H, inside the space E, is ground flat, and is closed by an indiarubber stopper I, which is kept pressed against the tube H by means of a spiral spring. The stopper I is fixed to a rod K; by pulling the rod down smartly the pressure inside the test-tube is lowered, and the piston P falls rapidly until it strikes against the india-rubber stopper D. The falling of the piston causes the gas in A to expand: the tubes R and S are for the purpose of regulating the initial pressure. Before an expansion the Piston P is raised by a trifling amount of air introduced through T, and the clip S is closed. Then, when everything is ready, K is pulled, and the cloud forms in A.

rate of movement of the top of the cloud will give the rate of falling of the individual globules of which it is composed. And this brings us to the next section.

Prof. Stokes and Falling Spheres.

Many years ago, in 1849, Sir George G. Stokes[1] discussed the motion of solids through fluids, and among others of a sphere moving through a viscous fluid urged by its own weight. It is a familiar fact that large bodies fall through air or water or any resisting medium more quickly than small ones of the same shape. Thus coarse sand settles down through water quicker than fine sand, and the finest powder takes a very long time to settle; in fact this difference of the rate of falling is used as a practical process of separating granular materials into sizes, and is called levigation.

So it is in air: large raindrops fall violently, small raindrops fall gently, and mist globules hardly fall at all—fall so slowly that their motion is difficult to observe,—but the same law governs all so long as the motion is not too violent, or so long as the falling body has no edges such as will cause eddies during the fall. A sphere falling slowly, controlled by viscosity alone without waves or eddies, is the simplest case. It soon reaches what is called a terminal velocity—the speed at which the viscous resistance exactly balances its weight.

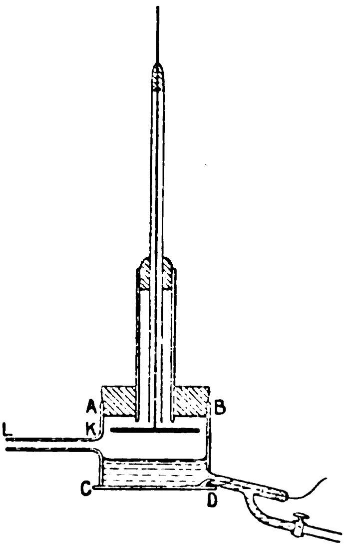


FIG. 4.—This figure corresponds closely with Fig. 2, Part III., only that a layer of water replaces the wire gauze. The vessel was attached to the expansion apparatus Fig. 3.

At this speed it is subject to zero resultant force, so it simply obeys the first law of motion and moves at a constant speed.[2] This constant speed or terminal velocity was calculated by Sir George Stokes for the case of a falling raindrop of radius r as follows:—

$$c = \frac{2}{9} \frac{g \rho r^2}{\text{viscosity of air}},$$

where ρ is the excess density of the sphere over the medium it moves in; provided there is no finite slip at the surface. The maximum possible effect of surface slip—which will occur to some extent when the falling globules are very minute—is to make the possible terminal

[1] *Camb. Trans. Phil. Soc.* ix. 48.
[2] Cf. *Nature*, vol. 31, p. 266.

velocity half as great again: in other words, to convert the numerical coefficient $\frac{2}{9}$ into $\frac{1}{3}$.

This simple formula gives the connection between the rate of fall of a raindrop and its size; and by observation of this speed, therefore, knowing the viscosity of air, it is possible to calculate the dimensions of the falling drops.

J. J. Thomson's Experiment of Counting.

We have now all the materials ready for understanding the experiment to be performed,[1] so as to count the ions which are produced in air under the impact of Röntgen rays, or when there are electrons to be counted which have been produced from a negatively electrified surface illuminated with ultra-violet light. The apparatus for the latter is depicted in Figure 4. A clean zinc surface in vacuo, faced by a piece of wire gauze through which the light could shine on it, and by a window of quartz which makes the vessel airtight, so that it might be exhausted and yet allow the ultra-violet light to pass, was employed as shown in Fig. 2 above: the present arrangement is similar except that a water surface replaces the gauze.

The rate of leak which gives the current Neu is determined by connecting the water and the zinc plate to the terminals of an electrometer; the zinc plate being kept negative by means of a battery of a sufficient number of cells.

And now, supplying this apparatus with the adiabatic expansion appliances of C. T. R. Wilson shown in Fig. 3 above, metrical condensation can be produced, a mist will form, and the rate of its fall can be observed; whence by Stokes's theorem the size of each globule is known; the quantity of water which had gone to form globules is known from the measured amount of expansion, by a process the details of which I will not give here; and so the number of such globules, and therefore the number of their condensation-centres or nuclei or ions, can be determined.

If c is the observed rate of fall in stagnant air, the linear dimensions of the falling drops will be

$$r = \sqrt{\left(\frac{9 \mu c}{2 g \rho}\right)} = \sqrt{\left(\frac{4{\cdot}5 \times {\cdot}00018}{981} c\right)} \text{ centimetres.}$$

In a given case c was observed to be $0{\cdot}14$ centimetres per second; hence the volume of each drop was in that case

$$\frac{4}{3} \pi r^3 = 1{\cdot}6 \times 10^{-10} \text{ c.c.};$$

and so if the aggregate amount of water in all the drops in a given space is reckoned from the measured amount of adiabatic expansion which caused the chill and the precipitation, the drops can be counted.

A great many precautions must be taken, because there will be

[1] *Phil. Mag.*, December, 1898, and December, 1899.

some residual cloud found even when electrons or intended nuclei are not present. A differential observation is therefore necessary; moreover care must be taken to ensure that all the nuclei are utilised, and not only a portion.

The number of drops found in a certain experiment by this means was about 30,000 to the cubic centimetre; the total quantity of water which went to form them being about the two-hundredth part of a milligramme.

Result.

The result of the execution of this ingenious counting process is that the absolute charge and the absolute mass of an electron is at length directly determined. Hitherto we have determined by many and various ways the ratio e/m and the speed u. We have likewise been able to determine Neu and Ne and Nmu^2, as already explained.

Now at length we have determined N; and at once the terms in the ratio e/m are disentangled.

e comes out, as suspected, in all cases, the regular ionic charge, of the order of magnitude 3×10^{-10} electrostatic, or 10^{-20} electromagnetic units; hence m comes out for positive carriers and for ions the appropriate mass of the atoms present. In some cases the masses are greater than this and represent molecular aggregates. But for the negative carriers set free by ultra-violet light, and for the other cases where $e/m = 10^7$, the masses come out definitely of the order 10^{-27} grammes; or about $\frac{1}{700}$th part of the smallest and lightest previously known quantity of matter, viz., an atom of hydrogen.

The existence of masses smaller than atoms was thus experimentally demonstrated, and a discovery was clinched of epoch-making importance.

PART VI.

Electric Theory of Matter.

Estimate of Size of Electrons.

On the hypothesis that the flying or vibrating fragment is a material corpuscle charged with electricity, so that it has a duplex constitution and a compound kind of inertia, part material and part electrical, no further progress can be made. But on the hypothesis that the flying or vibrating particle is an electron—a charge of electricity and nothing else—a constituent of an atom but with no material nucleus—so that the whole of atomic properties are to be considered as due to an aggregate of electrons of opposite size, of which one or two are comparatively free and detachable—on this hypothesis a determination of the mass of a corpuscle carries with it as a consequence a determination of its size also.

Because, as has already been pointed out, any required amount of self-induction can be conferred on a wire by making it fine enough,

and any required amount of energy can be conferred upon an electric charge by making it concentrated enough. The energy at a given speed of motion will be proportional both to the quantity and the potential, and the latter can be made as great as we please by making the size of the body possessing the charge extremely small.

It is the intense region of force close to the wire or close to the charged particle which is the effective region; and so, as stated, a knowledge of the mass or kinetic energy at a given speed suffices, on a purely electric theory of matter, to determine the size of the electron constituents of which it is composed. For whether there be any intrinsically material inertia or not, there certainly is an electrical inertia. The cause of it in the electrical case is known: it is due to the reaction of the electric and magnetic fields during acceleration periods, and is denominated self-induction.

Quite possibly there is no other kind. Quite possibly that which we observe as the inertia of ordinary matter is simply the electrostatic inertia or self-induction of an immense number of ionic charges or electric atoms or electrons.

This is by far the most interesting hypothesis, because it enables us to progress, and is definite. The admixture of properties, partly explained, viz. the electrical, partly unexplained, viz. the material—lands us nowhere, unless by some only partially imagined means we were able to estimate how much of the corpuscle appertains to each ingredient.

The mass of a corpuscle has been measured at something akin to $\frac{1}{1000}$ of an atom of hydrogen, and its charge as 10^{-10} electrostatic unit. This amount of electricity will have that amount of inertia if it exists over a sphere of radius 10^{-13} centimetre, but not otherwise. Consequently we may assume the size of the electron to be of the order 10^{-13} centimetre in diameter; or $\frac{1}{100000}$ of the linear dimension known as molecular magnitude, viz. 10^{-8} centimetre.

The calculation of order of magnitude is quite simple, for all ordinary speeds, because, for them—

$$m = \mu e^2/a,$$

$$\therefore a = \frac{e}{m} \cdot e = 10^7 \times 10^{-20} = 10^{-13} \text{ centimetre},$$

though it might with some data be estimated as small as 10^{-14}.* With a size like that the penetrating power of cathode rays is explained. Especially if the atoms of matter are themselves composed of such minute particles. For the interspaces will be enormous compared with the filled-up space, and a point can penetrate far into such an assemblage without striking anything.

The mean free path of a particle is a question of probability. In a space containing n_1 obstacles to the unit volume, a space Ax will contain $n = \mathrm{A}\,x\,n_1$ of them, and the chances of a collision while one of them travels a length x will be approximately their combined areas as targets compared with the total area available for both hit or miss—

$$\frac{n \pi a^2}{\mathrm{A}} = a x = \frac{x}{\bar{x}},$$

* See Lodge in the *Electrician* for March 12, 1897, vol. 38, page 644.

where $\bar{x}$ is the "mean free path," or average distance travelled by any one particle without a collision with another, and a the number of encounters while travelling unit distance. But in saying this we are ignoring the forces between the particles, and are not considering a swing round as a collision.

So, as regards order of magnitude—

$$x = \frac{A\,x}{n\,\pi\,a^2} \doteqdot \frac{1}{n_1\,\pi\,a^2} = \frac{d^3}{\pi\,a^2},$$

with a factor $\frac{3}{4}$ or $\sqrt{2}$ omitted which a completer theory would give; where d^3 is the cubic space allotted to each particle, while $\frac{4}{3}\pi\left(\frac{a}{2}\right)^3$ is the actual bulk of each.

$$\text{Therefore } \frac{\bar{x}}{a} = \frac{\text{total space occupied}}{\text{eight times the aggregate volume of the particles}},$$

a statement sometimes quoted as Loschmidt's theorem.

Hence the mean free path can be determined by considering how much space the substance of all the electrons in an atom occupies, as compared with all the space which the atom occupies itself. In other words, we have to consider what the size 10^{-13} for an electron's diameter means, as compared with the size 10^{-8} for an atom's diameter. In the solar system the diameter of the earth is $\frac{1}{20000}$th part of the diameter of its orbit round the sun. Consequently if the earth represented an electron, an atom would occupy a sphere with the sun as centre and five times the distance of the earth as radius.

In other words, if an average atom is composed of electrons, they are about as far apart in that atom in proportion to their size as the planets in the solar system are in proportion to their size.

In an atom of hydrogen there are roughly 1,000, or say more exactly 700 electrons in order to make up the proper mass.

In an atom of sodium, which is twenty-three times as heavy, there must be about 15,000 electrons.

And in an atom of mercury there must be over 100,000 electrons.

Consider then an atom of mercury containing 100,000 of these bodies packed in a sphere 10^{-8} centimetre in diameter. One would think at first they must be crowded; but there is plenty of room. Each electron is only 10^{-13} centimetre across, and there are only about fifty of them in a row along any diameter of the atom; hence the empty space inside the atom is enormously greater than the filled spaces. At least a thousand times greater in linear dimension, or a thousand million times greater in bulk.

The whole volume of the atom is 10^{-24} c.c., the aggregate volume of all the electrons composing the atom is $10^5 \times 10^{-39} = 10^{-34}$ c.c., consequently the space left empty is 10^{10} or ten thousand million times the filled space.

Even inside an atom of mercury, therefore, the amount of crowding is fairly analogous to that of the planets in the solar system. For though the outer planets are spaced further apart than the inner ones, they are also bigger, to practically a compensating extent.

Now, going back to what is sometimes called Loschmidt's theorem in the kinetic theory of gases, obtained roughly above—

$$\frac{\text{mean free path}}{\frac{1}{8}\text{ diameter of particle}} = \frac{\text{volume of space available to particles}}{\text{combined volume of all their substance}}$$

we have reckoned the latter fraction, in the inside of an atom of mercury, as—

$$\frac{\frac{4}{3}\pi \times \left(10^{-8}\right)^3}{100{,}000 \times \frac{4}{3}\pi\left(10^{-13}\right)^3} = \frac{10^{-24}}{10^5 \times 10^{-39}} = 10^{10}.$$

Hence the mean free path of an *electron* inside an atom of mercury will be comparable to 10^9 times the size of an electron, *i.e.*, it will be 10^{-4} centimetre; that is, it may get through on the average the substance of some 10,000 mercury atoms in a row without collision.

In any other less dense substance it will go further. The actual *distance* thus travelled by corpuscles plunging into a dense metal is very small, only the thousandth part of a millimetre on the average, and it need by no means necessarily be a straight line; so a target of platinum succeeds in stopping them fairly near its surface, and enables the X-rays generated by the shock fairly to emerge. Some corpuscles will be stopped more suddenly than this, and some will travel further, but 10^{-4} centimetre is about the average distance travelled in a solid as dense as platinum.

This distance, however, gives no notion of the value of the negative acceleration during a collision, because the greater part of the thousandth of a millimetre is free flight; the stoppage occurs only as the last episode of that flight, viz. at the instant of collision. The colliding masses are 100,000 to 1, so the change of velocity at impact could be estimated; but the impact will really be more of an astronomical or cometary character, and the effect is analogous to the entrapping of comets when they pass near a planet, thereby rendering them permanent members of the solar system.

The *ordinary* behaviour of a foreign comet, which comes and goes, may be called a collision with, and rebound from, the sun; for although there is no real encounter of main substance, that is what it would appear like if it could be seen from the depths of space; and the two branches of the comet's hyperbolic orbit would look like straight lines of approach and recession.

Comets which happen to pass very near a planet, however, are deflected, swirled round, and often virtually caught by that planet, receding only with an insignificant differential velocity which is unable to carry them away from the attraction of the sun: into which they often drop. Or if they do not actually drop into it, they will continue to revolve round it in an elliptic orbit, becoming a member of the solar system, and liable ultimately to be degraded into a swarm of meteors.

This is the sort of process known to occur in astronomy, and circumstances not unlike that may attend the encounter or apparent

collision of a furiously-flying comet-like electron with part of the massive system of an atom.

The stoppage, therefore, will occur well within the limits of atomic magnitude, 10^{-8} centimetre; and so the acceleration will be of the order $\frac{u^2}{2l} = 10^{26}$ c.g.s., and the force needed thus to stop even a single electron will be the tenth of a dyne.

No wonder that violent radiation-effects are produced. The "power" required to stop an electron, flying with one-thirtieth of the speed of light, inside a molecular thickness, can be estimated thus—

$$\text{energy} \div \text{time} = \frac{1}{2} m u^2 \cdot \frac{u}{2l} = 10^{-27} \left(10^9\right)^3 10^8 = 10^8 \text{ ergs per second};$$

or thus—

$$F l \div t = \frac{1}{2} F u = 10^{-1} \times 10^9 = 10^8 \text{ again,}$$

which is equivalent to ten watts. (Though the time it lasts is only the 10^{-17} part of a second.)

But only a small fraction of this goes into radiation. The radiating power can be estimated thus, from Larmor's expression for it, as given in Appendix G, Part IV.—

$$\frac{\mu e^2}{v} (\dot{u})^2 = \frac{10^{-40}}{10^{10}} \times 10^{52} = 100 \text{ ergs per second.}$$

The rest therefore, it would appear, must take the form of heat.

It is worth considering what circumstances would give radiation an advantage over heat, and *vice versâ*. Because sometimes conspicuously the target gets heated, and sometimes X-rays are emitted. Let u be the speed and l the distance of stoppage, then—

$$\dot{u} = \frac{u^2}{2l},$$

then the force required to stop it is—

$$m \dot{u} = \frac{2 \mu e^2}{3 a} \frac{u^2}{2l}.$$

The "power" of the blow is—

$$\tfrac{1}{2} F u = \frac{\mu e^2 u^3}{6 a l},$$

whereas the radiation power is—

$$\frac{2 \mu e^2}{3 v} \cdot \left(\frac{u^2}{2l}\right)^2 = \frac{\mu e^2 u^4}{6 v l^2};$$

therefore $$\frac{\text{radiating power}}{\text{total power}} = \frac{a}{l} \cdot \frac{u}{v} = \frac{2a}{vt},$$

where t is the time of stoppage, and v is the velocity of light.

So effective radiating power depends chiefly on very sudden stoppage, and on the speed being near that of light. If the velocity is a tenth that of light, and if an electron can be stopped in something like its own diameter, about 10 per cent. of the energy will go in radiation, and the rest will take other forms, presumably heat.

As the velocity diminishes, more and more of the energy takes the form of heat; which agrees with the fact that at moderate vacua the target gets red-hot.

The ratio of the radiation power to the total power is as the dimensions of an electron to the distance light would travel during the period of the stoppage. So to get *all* the energy radiated it is necessary to stop a pellet moving with a tenth the speed of light in something like a tenth of its own diameter.

Justification for Electric View of Matter.

But now what justification is there for the extraordinarily far-reaching hypothesis that the electrons constitute matter, that atoms of matter are composed of electric charges, that the fundamental inertia-property of matter is identical with self-induction?

There is the reasonable philosophical objection to postulating two methods of explaining one thing. If inertia can be explained electrically, from the phenomena of charges in motion, it seems needless to require another distinct cause for it also. But this is not all that can be said; it is quite possible that direct experimental proof will be forthcoming before long. A method suggested by Professor J. J. Thomson had reference to the proportion of radiation to thermal energy developed when corpuscles encounter a target which suddenly stops them. In so far as they consist of non-electric matter they would produce only heat by their dead collision, without any direct generation of ethereal waves. In so far as they consist of electric charges they would disperse a certain amount of radiation energy; and so the proportion of radiation to heat might afford a criterion.[1] Hitherto, however, no adequate measurements have been made in this direction.

But there is another more likely avenue to a conclusive result. We know that when an electric charge moves with a speed approaching that of light, its inertia is theoretically no longer constant, but rapidly increases and becomes infinite when the light-velocity itself is reached, at least on the orthodox and accepted theory; and rather complicated and not quite accordant expressions for this high-speed inertia have been calculated by several mathematical physicists. See Appendix K for a discussion of this difficult subject.

It is possible that in certain cases of the production of cathode rays a speed not far short of that of light may be reached, and the increased inertia observed. Such an experimental determination has been seriously and quite recently undertaken by Professor Kaufmann,[2] who employed the method indicated above (Part III.) of comparing simultaneously the

[1] See J. J. Thomson, *Phil. Mag.*, April, 1899, p. 416.
[2] See *Comptes Rendus* for October 13, 1902.

electric and the magnetic deflection of the same set of rays submitted alternately or simultaneously to an electric and a magnetic field. Thus the velocity and the e/m ratio are both known, and Kaufmann concluded that when the speeds approached perceptibly near the velocity of light the electrochemical equivalent m/e increased by just the amount required in accordance with pure electric theory—the theory which attributes the whole of inertia to electric influence. There appeared to be no quantitative room for any extra inertia, such as that of an inert particle of non-electric matter travelling with each projectile, retaining its inertia constant at all speeds, and so contributing nothing to the rise of inertia perceived when the speed approaches within hail of that of light.

It is too soon to be sure whether these results are trustworthy or not. The attempt is brilliant, and it can hardly be doubted that before long evidence will be forthcoming, on this and on other lines, which will enable us to accept or reject the hypothesis of the electric nature and unification of matter.

Meanwhile the hypothesis is in itself so probable that it is justifiable to attempt to look ahead and observe some of the consequences of the view that all atoms of matter are built up of the same fundamental units, and are composed of aggregates of a definite number of variously grouped negative and positive electrons, arranged in kinetic patterns and keeping apart by reason of the vigour of their own orbital motions.

At first it is not easy to do more than imagine the electrons to be statically grouped into regular patterns: arranged it may be in triangular or square or hexagonal order; with other allied three-dimensional possibilities familiar to students of crystallography. See, for instance, William Barlow, *Brit. Assoc. Report* 1896, p. 731; also Lord Kelvin, *Phil. Mag.*, March, 1902, and elsewhere.

On Chemical and Molecular Forces.

The force of chemical affinity has long been known to be electrical. Ordinary electrical attraction between charged bodies may be called molar chemical action; only there is no combination in ordinary cases, because the opposing charges spark into one another, and so the attraction ceases when a certain proximity is reached. The idea that chemical forces are really electrical is as old as Sir Humphry Davy.

Real chemical attraction occurs between two atoms, each of which contains an odd number of electrons: one extra, or it may be more than one extra, electron of given sign. Such an atom has a centre of force whereby it can attach itself to other atoms and enter into pairing or chemical combination with them. It is probable that a negative charge is an excess, and a positive charge a defect; and that when pairing occurs the excess charge of one fills up the deficiency of the other, and composes a complete and neutral molecule.

Union of this kind, however, never seems quite as strong and permanent as the union of the electrons in the atom itself: the molecule easily separates at the same place again under the influence of decomposing influences, and does not seem able to split up in other ways into new substances; except in organic chemistry, where various

modes of splitting up a complex molecule can be brought about, and are practically utilised for the generation of new compounds, *e.g.*—

$$CH_3 . CH_3 = C_2H_5 . H.$$

It is probable that the same sort of thing is *possible* with simple bodies, but that the so-called "elements" constitute a peculiarly stable group, the ingredients of which so far have only partially been re-associated into isomeric or allotropic forms, and have not yet been detached from each other.

When chemical combination occurs between two oppositely charged atoms, there is no electric discharge between them: the two atoms retain each its own charge, and cling together for that reason. When they are separated, each is an ion and possesses its appropriate charge.

It is possible to charge an assemblage of neutral molecules with an excess or with a defect of one or more electrons, by processes of ordinary electrification, but the attachment of these supernumerary electrons is loose—and they can be shaken away by the agitation of ultra-violet light and in many other ways. Even splashing of liquids into spray shakes some loose.[1] And in the case of massive molecules their mutual collision or agitation under the influence of ordinary temperature is sufficient to shake away some of the loose electrons, which then fly off tangentially with whatever orbital velocity they may have had: giving rise to phenomena recently discovered under the name of *radio-activity* (see Part VII.).

Molecular Forces, Cohesion.

But there is another kind of adhesion or cohesion of molecules, not chemical but what is called molecular. This occurs between atoms not possessing ionic or extra charges, but each quite neutral, consisting of paired-off groups of electrons. At any moderate distance the force of attraction between paired electrons will be next to nothing, but at very minute distances it may be very great, ranging up to something almost indistinguishable from chemical combination, except that the cling will be a weak cling at a multitude of points instead of an intense cling at only one.

Consider the outer surface of an atom consisting of a regular group of interleaved electrons of alternately opposite sign. Its equipotential surfaces will be dimpled or corrugated or pimply sheets, which at a little distance away will be almost plain, the dimples increasing rapidly in depth and becoming like the cover of a mattrass when something less than molecular distance, something approaching the internal electron distances apart, is reached.

Two such atoms will therefore tend to settle down with their equipotential surfaces adjusted into uniformity, the pimples of the one fitting into the hollows of the other; and this is the state of things suggested by the facts of cohesion (Fig. 5).

To investigate the actual law of force would be difficult, and too

[1] Lenard on electrification near waterfalls.

many assumptions would have to be made for the geometrical arrangement of the electrons in the adjacent atoms; it could only be approximate, because we should probably, at least in the first instance, have to assume a static distribution. Nevertheless the attempt might be instructive, and might in a developed form be suitable for an Adams Prize Essay.

It is quite plain, however, that the result would be a force rapidly increasing and becoming great at small distances, and practically nil at any perceptible distance.

Molecular forces on this view are electrical, just as much electrical as are chemical forces; but they occur between chemically saturated molecules, and are due to the interaction or distant influence of paired electrons on each other across molecular distances.

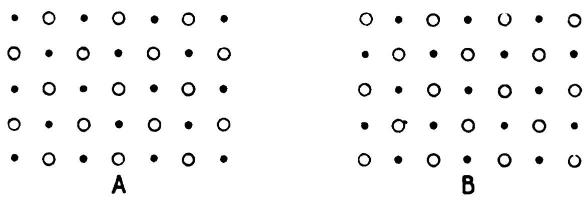


FIG. 5.—Ordinary Cohesion between two Neutral Atoms A and B: each atom consisting of interleaved electrons of opposite sign, depicted in any convenient way.

Ions cannot thus combine; because if they were oppositely charged their combination would be chemical, and if they were similarly charged they would strongly repel each other.

But if ions arrive at a metallic electrode, or are provided with other means of passing on their free charges, they cease to be ions and then they can and do combine molecularly with each other.

It is of course possible for an ion to have more than one free electron, forming a dyad or a triad radical; and the way in which a neutral group can receive and by rapid re-adjustment pass on an extra foreign electron, reminding one of the re-adjustment of the films in a lather when one compartment bursts, is doubtless instructive.

The effect of electric polarisation on such a neutral group of electrons is noteworthy. The effect of a charged body in the neighbourhood is at once to disturb the equilibrium and to disturb the grouping throughout the atom more or less: it will cause the negative electrons to protrude slightly on one side and the positive on the other (see Fig. 6).

If two molecules were beyond each other's molecular range, and if the neighbouring surfaces could by any means, by the supply of electricity from without, be oppositely electrified, the forces of cohesion would be intensified momentarily by something akin to chemical forces, and cohesion would set in over ultra-molecular distances. This appears to be what goes on in a "coherer." The opposite charges cannot be *maintained* electrostatically between two neighbouring

metallic surfaces, but they can be imparted with a sudden jerk or disruptive discharge or received electric impulse; and these are the things which are effective in promoting cohesion.

In the diagram herewith, Fig. 5 represents a couple of atoms with interleaved electrons of opposite sign in square order, the atoms being within range of one another and so cohering by molecular or non-chemical forces. They have adjusted themselves into a cohering position; but a shear through half the distance apart of the electrons would disintegrate them. An angle represented by half the electron-distance divided by the molecular-distance is therefore a measure of the maximum distortion of a substance.

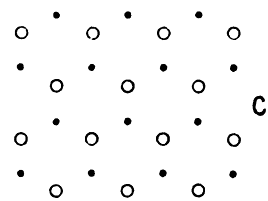


Fig. 6 shows a couple of atoms both electrically polarised, as by a positively charged rod held above both. The constituents of C are polarised into hexagonal order — an effect such as might also be caused by lateral pressure in some cases; the constituents of D are in diagonal square order: which has the effect of violent electric polarisation. The atoms C and D are therefore clinging by forces much stronger than ordinary cohesion at that distance would have been. They represent adjacent atoms of a momentarily polarised coherer.

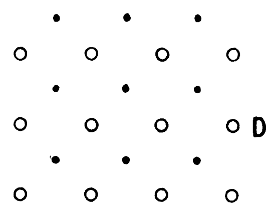


FIG. 6. — Two Polarised Atoms, polarised in different ways; illustrating also electrically intensified cohesion.

It is not to be supposed that the electrons need really ever be disturbed more than an almost imperceptible amount in order to produce this chemical cohesion effect.

APPENDIX TO PART VI.

APPENDIX K.

NOTE ON THE BEHAVIOUR OF A CHARGE MOVING NEARLY AT THE SPEED OF LIGHT.

Mr. G. F. C. Searle has kindly called my attention to a paper of his in the *Philosophical Magazine* for October, 1897, and maintains that a charge does not re-distribute itself on a moving body when its speed becomes great, but that the lines of force bend or are deflected towards the equator, without remaining normal to the surface whence they start. And I see that Mr. Heaviside in his Electrical Papers, vol. 2, p. 514, accepts this result and considers that we have no guarantee that at these high speeds lines of force are necessarily normal to conducting surfaces: an assertion in which we may trace some analogy to the fact that in a moving medium rays of light are not perpendicular to their wave fronts.

There is no question but that the lines of force bend back towards the equator, as stated by me in Part I., but I assumed that this deflexion of the lines would entail their moving up nearer to the equator of the sphere, so as to leave the poles bare of charge, in order that they might still continue radial. I admit that the lines of force need not continue radial, but it seems to me that there is still some redistribution of the charge as the speed increases: a fact, however, which is not important. Mr. Searle calculates that whereas a sphere at rest acts as if its charge were at a central point, this equivalent point opens out into a uniformly charged line, forming a medial and small portion of its diameter, when the sphere is in motion; the length of the line gradually increasing until the speed equals that of light, when it fits the sphere exactly. But this neglects a distortional change in the sphere itself, to which I will presently refer.

The fact is that the whole subject of the behaviour of a charged body moving at enormous speed is a complicated one, and directly you get within 20 per cent. of the speed of light it begins to be necessary to consider even its inertia, as well as its deflecting force, in a more thorough and elaborate manner.

Mr. Searle points out that three different estimates of inertia can be made:—one as the ratio of force to acceleration, another as the ratio of momentum to velocity, and a third as the ratio of kinetic energy to half the square of velocity. In ordinary matter as is well known, and for slow electric motions, these three estimates are one and the same; but for violent electric motions they become different; though it should be realised how small the difference is, until the speed of light is very closely approached; so that in no material case of great velocity or great acceleration that has ever been practically dealt with—as, for instance, the case of a cannon-ball stopped by armour plate—is any sort of unusual effect to be expected; even on the hypothesis that matter is entirely electrically composed. Nevertheless, now that among free corpuscles in a vacuum tube it is becoming practically possible to attain these high speeds, and even to begin to base crucial determinations upon them, it becomes necessary to consider the matter more carefully. And in a book published at Göttingen in January, 1902, Dr. Abraham discriminates what he calls "longitudinal" from what he calls "transverse" inertia; making inertia depend not only on the speed of motion, but on the direction in which the body is being accelerated.

And all these results are still further complicated by a consideration of the effect of acceleration itself, which, whenever it is violent, gives rise to some perceptible radiation, involving dissipation of energy; and this radiation loss of energy, though it will be primarily represented in the motion as a resistance or velocity term, may secondarily have an effect on inertia;—probably, however, quite a small and subordinate effect in all practical cases, and no effect at all so long as motion occurs with uniform speed in a straight line: for then there is no radiation. But then, of course, under those conditions it is not possible to test or measure the inertia of a body; it is only when the motion is either curved or changed in some way that inertia becomes prominent, and

then there is necessarily some, though usually very small, radiation too.

A convenient expression for the inertia of a body moving at any speed is hard to arrive at. A variety of expressions have been given, and some of them are contained in the first chapter to J. J. Thomson's "Recent Researches in Electricity and Magnetism," but they are not attractive, and it appears from Mr. Searle's results that it is only under very careful qualifications that they apply. For these reasons I do not propose to enter upon a discussion of them further than may be necessary to criticise or appreciate Kaufmann's recent experimental attempt at basing an important measurement on these high velocities, by observing the electric and magnetic deflexions then exhibited by cathode rays, so as to obtain if possible their modified m/e ratio at ultra high speeds.

When magnetic deflexion is being observed at ultra-high speeds we have also to remember that it is possible for the ordinary expression for the force exerted on a current by a moving field to be departed from.

The ordinary expression for deflecting force is $e\,u\,\mathrm{H}$ at low speeds, for a charge e moving at speed u across a magnetic field of intensity H; but at higher speeds an expression of much more complicated character is investigated by J. J. Thomson in the first chapter of his "Recent Researches in Electricity and Magnetism," and is obtained in the following form:—

$$e\,\mathrm{H}\,\frac{v^2-u^2}{u}\left(\frac{v}{2\,u}\log\frac{v+u}{v-u}-1\right)$$

This, however, at low speeds reduces not to the usual simple value, but to one-third of that value, viz. $\frac{1}{3}\,\mathrm{H}\,e\,u$; and Professor Schuster in the *Philosophical Magazine* for January, 1897, calls attention to the variety of numerical estimates of this quantity given by different varieties of the main theory.

Abraham's value of what he calls "transverse inertia" is quoted by Kaufmann in *Comptes Rendus*, vol. 135, p. 577, writing it with m_0 as the equivalent inertia for slow motion, and with β as the ratio u/v—the ratio of the speed of the motion to the velocity of light—thus

$$m=\frac{3\,m_0}{4\beta^2}\left(\frac{1+\beta^2}{2\beta}\log\frac{1+\beta}{1-\beta}-1\right)$$

and this is the formula employed by Kaufmann for experimental test and verification.

Mr. Heaviside gives a still more complex expression—Electrical Papers, vol. 2, p. 514—for kinetic energy; viz. an expression equivalent to $\frac{1}{2}\,u^2$ multiplied by the following quantity,

$$\frac{\mu c^2}{a}\cdot\frac{1-r}{4r}\left(1+\frac{2r-\frac{1}{2}}{1-r}+\frac{\left(2r-\frac{1}{2}\right)\tan^{-1}\sqrt{\left(\frac{r}{1-r}\right)}}{\sqrt{\left\{r\left(1-r\right)^3\right\}}}\right)$$

which therefore may be taken to represent the inertia for that case; r being the squared speed ratio u^2/v^2.

Larmor treats the whole matter from a general point of view in *Phil. Trans.*, 1895, p. 717, and shows that no mere acceleration term is sufficient to express completely the reaction to applied mechanical force.

Distortion due to High-speed Motion through the Ether.

In Mr. Searle's paper in the *Philosophical Magazine*, October, 1897, he points out that the simplest charged body when in motion is not a sphere, but an oblate spheroid, oblate in the direction of motion, with its axes in the ratio $\sqrt{\left(1 - \frac{u^2}{v^2}\right)}$, 1, 1; and that this produces on all points outside itself exactly the same effect as a point charge at its centre, and that therefore such a spheroid in motion at the speed u takes the place of the sphere in electrostatics. He calls this a Heaviside ellipsoid, because Mr. Heaviside first indicated its importance in the theory of moving charges.

But I wish to point out that a spheroid of this kind is exactly what a sphere in sufficiently rapid motion would automatically become, on the Fitzgerald-Lorentz theory; viz., that hypothesis which was started in order to account for the negative result in Michelson's experiment by postulating a change of dimensions in solid bodies according to their direction of motion through the ether. This hypothesis became a definite theory giving important results, when Lorentz showed that on the electric theory of matter—or even without assuming that the whole inertia of matter was electric, because the result is not a question of inertia, but of static force—not only was such a change of dimensions reasonably likely, as Fitzgerald had perceived, but that the change to be expected was precisely of the right amount to give a compensating effect and precisely zero resultant in the Michelson experiment.

The change of dimensions thus imagined and justified is gradually coming to be accepted as plausible and probably true; and it is interesting to note that a sphere in motion, by reason of being subject to this amount of distortion, still retains its property of being the simplest geometrical body, so far as the distribution of its electric field is concerned. True it is then no longer a sphere; but no measuring instrument could possibly show its distortion, because all standards of measurement would share it. It is a remarkable thing that this imperceptible and unmeasurable uniform distortion of all matter should ever have been discovered: nothing but an ethereal process could have dragged it to light. Nevertheless dragged to light it has been, by the combined testimony of electrical theory and of optical experiment.

PART VII.

SUMMARY OF OTHER CONSEQUENCES OF ELECTRON THEORY.

Radio-Activity.

If many atoms of a substance have electrons attached to them, and if these are performing orbital revolutions, it is natural to ask how then can it be that substances are not constantly emitting waves and radiating away their energy. Fortunately owing to the brilliant researches of Becquerel, Curie, and others, certain substances have been found in which the radiation intensity reaches a very perceptible magnitude; and it appears that this radiation may be of several kinds—

1st, of waves or pulses analogous to Röntgen radiation, probably;

2nd, of rays analogous to Lenard or cathode rays consisting of electrons and ions bodily shot off, certainly;

3rd, of detached portions of the substance itself not charged with electricity, but emanating like an odour, and possessing like the rest of the substance an intrinsic radiating power, and capable of attaching itself to other materials in the neighbourhood so that they too acquire temporary radiating power.[1]

The substances which possess any noteworthy amount of this radiating power are substances with very high atomic weight, and their emitting power would appear to be probably due to an internal commotion and collision between the atoms, of sufficient violence to detach, and as it were evaporate every now and then, some of the smaller particles; and also by the shock of the collisions to generate some feeble Röntgen rays.

It is easy to grant that whenever there are actual collisions of sufficient suddenness some radiation of this kind must be emitted; but we cannot help asking, why does not the quiet orbital revolution of electrons round atoms, in a substance not in a high state of thermal disturbance and not possessing specially massive atoms, why does not this also give rise to a perceptible amount of radiation and loss of energy? One answer that has been given is as follows:—

The radiators are not isolated or independent, and surface radiation is maintained by layers at greater depth in the substance. Moreover the radiators are so close together that they are in all sorts of phases within the first quarter wave length, a length which embraces a multitude of them; wherefore a multitude is a worse radiator than one, because they interfere and produce but little external or distant effect; like the two prongs of a fork, or two neighbouring organ pipes, or the front and back of a vibrating wire. See Larmor, *Ether and Matter*,

[1] See, for instance, papers by the original discoverer, M. Henri Becquerel, in *Comptes Rendus*, 1896 and 1897; see also Rutherford, *Phil Mag.* January, 1899 and 1900, with quantitative determinations concerning it. Also in *Phil. Mag.* July and November, 1902. Other references are M. and Mme. Curie, *Comptes Rendus*, November, 1899; Hon. R. J. Strutt, *Phil. Trans.* A 1901, vol. 196, p. 525; Sir W. Crookes, *Proc. Roy. Soc.*, vol. 66, p. 409 (1900), vol. 69, p. 413 (1902), also "Electrical Evaporation," 1891, *Proc. Roy. Soc.*, vol. 50, p. 88; and many other workers.

page 232. But I doubt if much answer is wanted, save one of a very different character, viz., that radiation of a low temperature order is as a matter of fact always going on from all substances; that energy is conserved and constancy of temperature persists merely because loss is equal to gain, because absorption compensates radiation, not because radiation ceases; and that to make an estimate of the amount of radiation so occurring it would be necessary to suppose the body in an enclosure at absolute zero: when undoubtedly its kinetic energy *would* rapidly leak away, and be dissipated. The whole subject of radio-activity is a large one, upon which I do not propose to enter here and now. Suffice it to realise that any difficulty of explanation in connection with it is not the fact itself, but rather why it is not more notorious.

However, so far as the most striking and interesting excessive photographic and electric radio-activity of certain rare substances is concerned, it has been already hinted that the greater part of that does not consist so much in the emission of radiation proper—whether in the form of pulses of X-rays or any other form—as in the flinging off of particles, negatively charged particles or electrons as a rule, but also sometimes, according to Mr. R. J. Strutt, of positive ions also. The faint photographic influence of ordinary substances observed by Dr. W. H. Russell seemed to suggest that incipient power of this kind is not limited to bodies with heavy atoms like Uranium, Radium, Polonium, etc., as described by Becquerel and the Curies, though these substances show it to an extraordinary degree: Dr. Russell, however, appears to have traced his at first interesting effects to the merely chemical action of hydrogen peroxide.

The whole subject, together with the allied one of the loss of charge from hot bodies,[1] first discovered by Dr. Guthrie long ago (see *Phil. Mag.* [4], xlvi. p. 273), is one that demands special attention and treatment, for which there is no opportunity now.

Solar Corona, Comets' Tails, Magnetic Storms, and Auroræ.

Another subject on which it is tempting to enlarge is the explanation of various astronomical and meteorological phenomena by the electron theory.

The theory of Auroræ has recently been elaborated by Arrhenius; but the whole doctrine of emanations from the sun, and of repulsion of small particles both by his light and by his probable electrification, is a matter that has been familiar to me for several years, through conversation with Fitzgerald and others. See, for instance, Larmor, *Phil. Trans.* 1894, vol. 185, p. 813; Lodge on Sunspots, Magnetic Storms, Comets' Tails, Atmospheric Electricity, and Auroræ, in the *Electrician* for December 7, 1900, vol. 46, p. 250: Fitzgerald, *Electrician*, December 14, 1900, with reference to a communication on the subject in 1893 (see the *Electrician* for August 11, 1893). See also his collected "Scientific Writings," at date 1882.

The earth is in fact a target exposed to cathode rays, or rather to

[1] See, for instance, Strutt on leakage from hot bodies, *Phil. Mag.* July, 1902; J. J. Thomson, ditto, *Phil. Mag.* August, 1902.

electrons emitted by a hot body, viz. the sun. The gradual accumulation of negative electricity by the earth is a natural consequence of this electron bombardment, and the fact that the torrent of particles constitutes an electric current of fair strength gives an easy explanation of one class of magnetic storms; which have been long known, by the method of concomitant variations, to be connected with sunspots and auroræ. The electric nuclei would also serve as centres for condensation of atmospheric vapour at high altitudes and so be liable to affect rainfall.

Nevertheless it is true that these theories have been well elaborated of late by Arrhenius; and his explanation of the aurora by means of the catching and guiding of rapidly moving electrons by the earth's magnetic lines of force, so as to deflect them from the tropics and conduct them in long spirals, along the lines, to the poles, there to reproduce the phenomena of the vacuum-tube in the rarified upper regions of the atmosphere, is particularly definite and pleasing. Some of the other astronomical suggestions he has made are likewise of considerable interest.

Validity of Old Views.

Now that the doctrine of electricity (at least of negative electricity) as located in small charges or charged bodies is definitely accepted, and now that a current can be treated as the locomotion of actual electricity, it may seem as if some doubt were thrown upon the doctrine, which a little time ago was spoken of as a "modern view," that the energy of an electric current resides in the space round a conductor. There is no inconsistency, however. The whole of the fields of an electron are outside itself; it is in its fields that its energy resides, and it is in the space round it that energy is conveyed when it moves; for the ether in that space is subject to the co-existence of an electric and a magnetic field. So, also, its inertia resides in space round it, for it is accounted for by the E.M.F. set up when its magnetic field changes, that is when its motion is accelerated.

In dealing with the inertia of matter it is commonly supposed that the inertia resides in the matter itself: whereas electrical inertia is known to reside in the space round the nucleus. Yet we have been emphasising and opposing the view that material inertia and electrical inertia are essentially one and the same.

Is there no inconsistency here?

The appearance of inconsistency vanishes when we come to calculate and realise how extremely local and concentrated the intense part of the field of an electron is. There is a sense in which it can be said that a moving body, for instance a vortex ring, disturbs the whole atmosphere; but any perceptible disturbance resides very near the ring. So it is with an electron. The magnetic field falls off inversely as the square of the distance from the moving nucleus, and hence at a distance far less than a millimetre, less even than the size of an atom, it is quite inappreciable. The whole magnetic field on which its inertia depends lies practically very close to the electron itself: it is just its extremely small size that enables this concentration to be possible, and even in a

closely packed mercury atom there is practically no encroachment of the field of one electron on its neighbour's. They are all independent, each with its own inertia, almost isolated from the others: for if it were not so, the mass of a body in close chemical combination would not continue constant, but would diminish. Whether it does diminish in the least degree is a question perhaps worthy of attack.[1]

The momentum of a moving charge at ordinary speeds is simply inversely as the radius of the sphere which holds it, as stated in Part I., but the localisation of this momentum, which is the point we are now considering, is given generally in Thomson's *Recent Researches in Electricity and Magnetism*, p. 20, and may be realised approximately as follows:—

The momentum depends on the co-existence and product of the electric and magnetic fields. Each field varies inversely as the square of the distance from the moving charge; and their vector product is, as regards direction, perpendicular to the radius vector at any point, and proportional at ordinary speeds to the sine of the angle between the radius vector and the direction of motion, while in magnitude it falls off as the inverse fourth power of the distance. All this can be realised by common sense with very little trouble.

So, then, take a moving electron, and consider the distribution of its momentum in the space round it. Between its surface and a space of a hundred times its diameter, 99 per cent. of its momentum is contained; because we shall have to integrate the factor—

$$\int_a^r \frac{4\pi r^2 dr}{r^4}$$

So, within the boundary of an atom, which is a hundred-thousand times an electron's diameter, there is practically none of its momentum not included.

And even in one of the comparatively closely packed atoms, *e.g.* in a platinum or mercury atom, the overlapping of momentum for each constituent is extremely small, since their average space apart is some thousand times the size of each constituent electron.

Consequently the assertions that an electric current is a transfer of electrons, and that the energy of a current travels in the space surrounding the moving electricity, are statements not inconsistent with each other. Nor are the statements inconsistent that the mass of a body resides in its atoms, and that inertia or momentum is a property due to the self-inductive influence of the electromagnetic field surrounding a moving electric nucleus. So also with the way in which a current is propelled. The pace of progression of electrons through a solid may be considerable, see next section, but it is very far below the pace at which a telegraphic signal travels along a wire. They must be propelled by a lateral action, transmitted through the ether with the speed of light appropriate to the surrounding insulator, by some arrangement which "Modern Views" symbolised in the form of cog-wheels: they cannot be impelled by end thrust. The electric current

[1] Cf. Rayleigh, British Association, Belfast 1902.

is a more material entity, or has a more nearly material aspect, than was thought probable a little while since; but all that was taught about its mode of propulsion and the diffusion of the propelling force from outside to inside through successive layers, as it were, of the wire, all that was taught about the paths by which the energy travels and arrives at point after point of the wire, there to be dissipated as heat, remains true.

Number of Ions in Conductors.

The immense number of electrons that are necessary to make up the mass of a piece of platinum, or of a lump of matter like the earth, can readily be estimated; so, also, it is easy to imagine that an enormous number must be travelling in order to give customary strengths of current such as can readily pass through a liquid.

Through a gas a limit is soon found to the available number, and accordingly the conductivity of an ionised gas falls off if we call upon it to carry more than a certain current, called the saturation current. See investigations by Townsend and others. But I am not aware of any experimental indication of such a limit in solids or liquids at present. In solids the pace of travel is unknown, though it has been ingeniously surmised, and is thought to be very great; considerations of centrifugal force would make the speed of each electron during an atomic encounter equal to $c/\sqrt{(\mathrm{K}\,m\,r)}$ or about 10^8 centimetres per second; views based on Maxwell's theorem about equal distribution of energy among the particles of mixed gases suggest 10^7 for the average speed of electrons at ordinary temperatures in a solid where they were free, that is a hundred kilometres or sixty miles per second; though, since each particle is subject to constant changes of direction, this is by no means the pace of straightforward *progression*. But in liquids they are attached to atoms, and the pace of progression is known both theoretically and experimentally with considerable accuracy, and is comparable to an inch an hour for customary gradients of potential.

The total current is $n\,e\,u$; and to give a unit c.g.s. current at so low a speed we can reckon how many ions there must be.

For $e = 10^{-20}$ electromagnetic units;

so if we take $u = 10^{-3}$ centimetre per second,

then the number of ions engaged in conveying the c.g.s. unit of 10 amperes is $n = 10^{23}$. But, after all, this is nothing very great. It is only about the number of atoms in a cubic centimetre of liquid, and by applying a greater gradient of potential the ions can be made to move faster. By gradually narrowing down the section of a liquid conductor under a given gradient of potential, it might seem possible to get evidence of an approach to a saturation-current-density in liquids. The observed accuracy of Ohm's law[1] under such conditions, however, is against this experimental possibility.

Conclusion.

The subject is very far from exhausted, but I must not attempt to cover more ground. The most exciting part of the whole is the

[1] Fitzgerald and Trouton, Brit. Assoc. Reports, 1886, 1887, 1888.

explanation of matter in terms of electricity, the view that electricity is, after all, the fundamental substance, and that what we have been accustomed to regard as an indivisible atom of matter is built up out of it; that all atoms—atoms of all sorts of substances—are built up of the same thing. In fact the theoretical and proximate achievement of what philosophers have always sought after, viz., a *unification of matter.* And another surprising and suggestive result is that the spaces inside an atom are so enormous compared with the size of the electrical nuclei themselves which compose it; so that an atom is a complicated kind of astronomical system, like Saturn's ring, or perhaps more like a nebula, with no sun, but with a large number of equal bodies possessing inertia and subject to mutual electric attractive and repulsive forces of great magnitude, to replace gravitation. The radiation of a nebula may be due to shocks and collisions somewhat like the X-radiation from some atoms.

The disproportion between the size of an atom and the size of an electron is vastly greater than that between the sun and the earth. If an electron is depicted as a speck one-hundredth of an inch in diameter, like one of the full-stops on this page for instance, the space available for the few hundred or thousand of such constituent dots to disport themselves inside an atom is comparable to a hundred-feet cube; in other words, the atom on the same scale would be represented by a church 160 feet long, 80 feet broad, and 40 feet high, in which therefore the dots would be almost lost. And yet on the electric theory of matter they are all of the atom that there is; they "occupy" its volume in the sense of keeping other things out, as soldiers occupy a country; they are energetic and forceful though not bulky, and in their mutual relations they constitute what we call the atom of matter; they give it its inertia, they enable it to cling on to others which come within short range, and by excess or defect of one or more constituents they exhibit chemical properties and attach themselves with vigour to others in like or rather opposite case.

That such an atom, composed only of sparse dots, can move through the ether without resistance is not surprising. They have links of attachment with each other, but so long as the speed is steady they have no links of attachment with the ether; if they disturb it at all in steady motion it is probably only by the simplest irrotational class of disturbance which permits of no detection by any optical means.[1] Nor do they tend to drag it about. All known lines of mechanical force reach from atom to atom, they never terminate in ether; except indeed at an advancing wave front. At a wave front is to be found the reaction of a mechanical pressure of radiation whose other component rests on the source. This is an interesting but essentially non-statical case, and it leads away from our subject.

As to the nature of an electron regarded as an ethereal phenomenon, it is too early days to express any opinion. At present it is not clear why positive electrons should cling so tenaciously to a group, while an outstanding negative electron should readily escape and travel free.

[1] See *Phil. Trans.* 1893, vol. 184, pp. 750–754; also vol. 189, p. 166.

Nor is the nature of gravitation yet understood. When the electron theory is complete to the second order, or some higher *even* order, of small quantities, it is hoped that the gravitative property also will fall into line and form part of the theory; at present it is an empirical fact which we observe without understanding; as has been our predicament not only since the days of Newton but for centuries before.

Attention has hitherto been chiefly concentrated on the freely-moving active negative ingredient,—the more sluggish positive charges are at first of less interest,—but the behaviour of electrons cannot be fully and properly understood without a knowledge of the nature and properties of the positive constituent too.

The positive electron has not, so far as I know, been as yet observed free. Some think it cannot exist in a free state, that it is in fact the rest of the atom of matter from which a negative unit charge has been removed; or, to put it crudely—that "electricity" repels "electricity," and "matter" repels "matter," but that Electricity and Matter in combination form a neutral substance which is the atom of matter as we know it. Such a statement is an extraordinary and striking return to the views expressed by that great genius, Benjamin Franklin. On any hypothesis those views of his are of exceeding interest, and show once more the kind of prophetic insight which we have had occasion to notice in discoverers before (Appendix H above). Undoubtedly we are at the present time nearer to the view of Benjamin Franklin than men have been at any intervening period between his time and ours.

The view that an atom is composed of an equal number of interleaved or inter-revolving positive and negative electrons—to which it will have been observed I myself tentatively and provisionally incline—that view is not Franklin's; nor is it as yet anything but a guess. To make it more, work must be done upon the nature and properties of the positive charge; and the positive electron, if it exists, must be dragged experimentally to light.

Especially must the inner ethereal meaning both of positive and negative charges be explained: whether on the notion of a right-and left-handed self-locked intrinsic wrench-strain in a Kelvin gyrostatically-stable ether, at present being elaborated by Larmor,[1] or on some hitherto unimagined plan. And this will entail a quantity of exploring mathematical work of the highest order.

The PRESIDENT: I have heard the suggestion made that there might be one or two people in this Institution who do not think electrons are things worth troubling about, but we must remember that the subject which has been dealt with to-night is the very basis of modern science. The question of electrons is to us by far the most important question of the day. Electrons are hypothetical bodies which help us to think straight. We owe a great debt of gratitude to Sir Oliver Lodge for coming here to-night. He has really only done his duty, because it is the duty of any one who is—to use Sir Oliver's

The President.

[1] See *Ether and Matter*, p. 326; or *Phil. Trans.* 1894, pp. 810, 811, and 1897, pp. 209–212.

The President

own expression—a pioneer of Science, to come and help other people on by explaining to us from time to time how far he has got. But Sir Oliver Lodge, in addition to doing his duty, is able to do his duty exceedingly well. There are very few people who not only understand a very difficult subject but who also can translate it into English. Some time ago Jevons remarked that the elementary edition of Thomson and Tait's "Natural Philosophy" was quite as mathematical as the fat volume we know so well. What he probably meant was that it took just as much genius (if not more) to write an apparently elementary treatise in plain English as it did to write a book using mathematical expressions. Sir Oliver Lodge is admirable in his exposition of an exceedingly difficult subject, and not only this Institution but the whole of the scientific world who are interested in these matters owe a debt of gratitude to him for giving us a paper which will enable us to some extent to get our knowledge up-to-date in the most important branch of science that there is at the present time. We all remember Sir Oliver's *Modern Views On Electricity*. That book is going to be something like the *Encyclopædia Britannica*: it is going to have supplements from time to time bringing it up-to-date. I will now put to the meeting that we pass a cordial vote of thanks to Sir Oliver Lodge.

The vote was carried by acclamation.

Sir O. Lodge.

Sir OLIVER LODGE: I am very much obliged to you, gentlemen. I would also like to express my thanks to Sir William Crookes and also to Mr. Gardner for having taken the trouble to bring the apparatus for the purpose of illustrating the paper.

The PRESIDENT announced that the scrutineers reported the following candidates to have been duly elected:—

Members.

Kay Oscar Arthur Gulstad.
Edward George Jones.
Wilfred James Lineham.
David Reid.
Arthur Wilkinson Whieldon.

Associate Members.

Sydney Ernest Britton.
Walter Charles Brown.
William Woodyer Buckton.
William Edward Beck Dove.
Alfred Lindsay Forster.
George Edward Heyl-Dia.
William Mannox.
Charles Wheusa Nicholl.
Henry William John Peterson.
Percy Edward Rycroft.
William Hugh Smith.
Gilbert Richard Spurr.
William Wharam.
Harold Langton Tyson Wolff.

Associates.

Herbert Bailey.
Alfred William Bennis.
Eric Francis Boult.
Charles Borthwick Chartres.
Harry De Pinna.
George Dixon.
Henry Benjamin Dorrell.
John Francis Edmonds.
Alfred Eve.
John Gilligan.
Albert Gray.
Samuel Barnes Griffith.
Louis Thomas Healy.
Francis Christian Heritage.
Archibald Johnston.
Louis J. Lawless.
George Catterall Leach.
Arnold B. Longden.
William McDonald.
James McLachlan.
Warwick Makinson.
William Henry Merrett.
Ernest Henry Mottram.
Ernest Holt Owtram.
Percy Claude Parker.
Richard Rigg.
Ernest Castle Roche.
John William Percy Scott.
William Bellhouse Scott.
Charles Henry Shanan.
Edward Vernon Flamank Shaw.
Hugh Christopher Silver.
Albert Smith.
Thomas Smith.
James Daniel Stevens.
Walter William Wakley.
Frank Walker.
Harold West.
Cecil Harington Williams.
James Cooper Wilson.
Robert Ernest Workman.

Students.

Nai Barr.
William Blathwayt.
James Bollands, jun.
Richard England Brooke.
Edward Fisher.
Victor William Gill.
Jeremiah Hague.
Ralph Hardy.
Ralph Pacey Hulton.
Philip Vassar Hunter.
Philip Henry Keeling.
Richard Line.
Thomas Mason.
William Harry Maystone.
William George Perry.
Ernest William Porter.
Ernest Byers Thomas.
Egerton John Ward.
Reginald Choldmeley Campbell Yates.

THE Three Hundred and Eighty-third Ordinary General Meeting of the Institution was held at the Institution of Civil Engineers, Great George Street, Westminster, on Thursday evening, December 11th, 1902—Mr. JAMES SWINBURNE, President, in the chair.

The minutes of the Ordinary General Meeting held on December 4th, 1902, were read and confirmed.

The names of new candidates for election into the Institution were announced, and it was ordered that these names should be suspended in the Library.

The following transfers were announced as having been approved by the Council :—

From the class of Associates to that of Associate Members.

Augustus Archer.
Henry Martin Bayly
Robert John Halliburton Beaty.
Harry Jeffery Bellow.
Harold Bentham.
Herbert Carpmael.
Frederick Samuel Carter.
Herbert John Coates.
W. J. Coles.
Arthur Douglas Constable.
John Frederic Coote.
Frank Whinfield Crawter.
Jas. Mountjoy Elliott.
James S. Enright.
Louis Henry Euler.
Oswald Lofthouse Falconar.
Chas. Walter Fourniss.
Archibald John French.
Arthur Thomas Gordon-Smith.
Wm. Jas. Grey.
James Hall.
Sydney Enoch Hall.
Patrick Hamilton.
Lionel Edward Harvey.
Alfred William Hill.
Frederick Hutchins.
Frederic Osmond Hunt.
Julius Pierpoint Lawrence.
Arthur Hector Lidderdale.
Henry A. Lewis.
Richard Percy Lovell.
G. A. Maquay.
William C. Martin.
Alick James Newport-Kennett.
Edwyn S. Pope.
Douglas Potter.
William Pearson Richmond.
George Weston.

Messrs. F. B. O'Hanlan and A. K. Taylor were appointed scrutineers of the ballot for the election of new members.

A Donation to the *Library* was announced as having been received since the last meeting from Mr. R. T. Atkinson, to whom the thanks of the meeting were duly accorded.

The following paper was read :—

THE PHOTOMETRY OF ELECTRIC LAMPS.

By Dr. J. A. FLEMING, M.A., F.R.S., Member, Professor of Electrical Engineering in University College, London.

Although a large number of the Members and Associates of this Institution are connected with electric lighting, and therefore unquestionably interested in the efficiency of electric lamps as light-producing agents, it is somewhat remarkable that in the last twenty years we have had only one discussion on the subject of Photometry.[1] We have had many papers on the use and physics of incandescence and arc-lamps, and the means for measuring the energy supplied to them, but not one exclusively devoted to the processes for determining their photogenic value. We frequently see glow-lamp efficiencies expressed in figures running to two decimal places, yet it needs but little acquaintance with the subject of light-measurement to compel an admission that the probable accuracy of the determination of the illuminating power is not often sufficient to justify it.

The following incident in this connection, which came under the personal notice of the writer a few months ago, is significant. A certain firm ordered from well-known manufacturers of glow-lamps some special lamps which were to be carefully marked for volts and candle-power. These lamps when delivered were submitted to another testing laboratory for verification, and the difference between the candle-powers affirmed by the manufacturers and those given by the testing laboratory amounted in some cases to 25 per cent. In another instance, some lamps were brought over from the United States, which were stated to be 16 c.p. at a certain voltage. They were sent to a lamp factory in London to be tested for candle-power at the marked voltages, and the candle-powers were returned in all cases at numbers between 18 and 19. In other words, there was a difference of about 20 per cent. between measurements made in New York and those made in London. These differences may have been to some slight extent due to the electrical measurements, but there is no question that the principal part of the error was in the photometric determinations. These measurements were not made by careless observers, but by competent persons, and the facts show that no excuse is needed for again bringing the subject of the photometry of electric lamps before this Institution.

If such variations exist in the case of incandescent lamp tests, they indicate that many arc-lamp candle-power and efficiency measurements, which involve all the difficulties of heterochromatic photometry, may be even more uncertain in value.

The exact marking of glow-lamps with their actual candle-power is important, because otherwise comparisons between various makes of

[1] "On a New Form of Portable Photometer," by Sir David Salomons (and subsequent discussion), *Journal Inst. Elec. Eng.*, vol. 22, p. 197 (1893).

lamps are misleading. In the case of arc-lamps the value of improvements cannot be properly estimated if one of the factors in the efficiency is uncertain within wide limits.

The subject is therefore ripe for discussion, and the more so because the Metropolitan Gas Referees, a body of experts appointed to control the testing of London gas, not long ago made important alterations in the official methods of gas-light photometry. These changes have only been made after prolonged inquiries, hence it is most desirable that electrical engineers should be acquainted with these methods, and that gas engineers and electrical engineers should be in agreement at least on the one subject of the unit or standard of light. Moreover, International agreement as to processes, as well as standards for electric-light photometry is required, since photometry when the lights are of very different spectral composition is complicated by peculiar difficulties, and hence involves the means of measurement as well as the standards of comparison.

The subject naturally divides itself into the consideration of—

1. Standards.
2. Processes of measurements.
3. Special considerations affecting heterochromatic photometry.
4. International agreements on the subject of standards of light and processes of testing.

I. Standards.

Whilst the sperm candle, six to the pound, burning 120 grains of spermaceti per hour, still retains its position as the legal standard in the United Kingdom, owing to its mention in the Metropolis Gas Act of 1860, and the Gas Works Clauses Amendment Act of 1871, it has been practically now dethroned from the position it has long unworthily occupied, by the action of the Metropolitan Gas Referees in adopting the 10-candle power Vernon Harcourt Pentane lamp as the official light standard for the testing of gas. We need not, therefore, spend a moment in abusing the Parliamentary candle. It has been extensively investigated and universally condemned.[1] Although the Gas Referees have no jurisdiction outside London, yet some large towns, such as Birmingham, Hastings, etc., follow their lead, and probably in a short time the use of the sperm candle which was once obligatory in gas-testing will have entirely ceased.

In spite of the elaborate specification for its preparation and use, issued by the Gas Referees in England, general experience shows that candle standards of any kind are inferior to other flame standards using a liquid fuel.

[1] For an exhaustive criticism of the "candle" as a standard of light, the reader may be referred to "A Report on Standards of Light presented to the American Institute of Electrical Engineers," by Prof. E. L. Nichols, and Messrs. C. H. Sharp and C. P. Matthews (see *Trans. Am. Inst. Elec. Eng.*, vol. 8). See also "A Method for the Use of Standard Candles in Photometry," by C. H. Sharp (*Physical Review*, vol. 3, p. 458).

The same remarks apply to the German paraffin candle, the so-called "Vereinskerze" or Association candle, once the official standard in that country; defined at the suggestion of, and its mode of use carefully specified by, the German Association of Gas and Water Engineers; but now displaced by the Hefner lamp, which has become the legal standard of light in Germany.

The standards of light or illuminating power now in use are divided into—

1. Flame standards.
2. Incandescence standards.

And we may furthermore divide them into Primary or Reference standards and Secondary or Working standards.

The flame standards which have been exhaustively investigated up to the present are :—

(*a*) The Colza oil or Carcel standard, which remains the official standard for gas-testing in France, and still preserves the form given to it by Dumas and Regnault.
(*b*) The various Pentane lamps of Mr. A. G. Vernon Harcourt, F.R.S., well known and much used in Great Britain, one of which is now the official standard for London gas-testing.
(*c*) The Amyl Acetate lamp of Herr von Hefner-Alteneck, introduced in 1884, and extensively employed in Germany, where it is the legal standard.

Other flame standards which have been suggested and more or less used are :—

(*d*) The Argand coal-gas flame with Methven slit, the coal-gas being sometimes enriched with pentane.
(*e*) The Benzene and Ether flame recommended by Dutch Photometric Commission in 1893.
(*f*) The Acetylene flame standard of Charpentier.
(*g*) The Acetylene and Hydrogen flame, two parts acetylene and one part hydrogen, burnt in pure oxygen, recommended by the American Institute of Electrical Engineers.
(*h*) The Ethylene flame, consisting of pure ethylene burning in pure oxygen, suggested by M. A. Blondel.
(*i*) The Albo-carbon lamp, burning naphthalene, proposed by M. Broca.

It is generally agreed that a flame standard must comply with three conditions :—

1. The combustible must be of constant and definite chemical composition easily obtained pure, and tested for purity without difficulty.
2. It must be burnt under simple and easily controlled conditions.
3. Unavoidable changes in atmospheric pressure and composition must not affect the character of the flame sensibly.

Moreover, it should be capable of being set up anywhere and be self-contained. This last condition rules out any coal-gas standard, even if experience has not shown that the Methven screen by no means renders the light emitted by a coal-gas flame independent of the composition of the gas.

Also in spite of the fact that the Colza oil lamp has maintained its position in France as the official standard of light for the greater part of the century, the uncertain composition of this combustible has prevented its adoption in other countries. The three flame standards which at present hold the field are :—

1. The 1-candle Pentane Reference Standard, introduced by Mr. A. G. Vernon Harcourt in 1877.
2. The more recent 10-candle Pentane lamp by the same inventor, now adopted as the official working standard by the Gas Referees, brought out in 1898.[1]
3. The Amyl Acetate lamp, introduced by Herr von Hefner-Alteneck in 1884.

Mr. Harcourt's work on Photometry, which has extended over nearly thirty years, is too well known to need eulogium, and is based upon the employment of pentane as a standard fuel. This very volatile and inflammable liquid, having the chemical composition C_5H_{12}, is the distillate yielded by light American petroleum after three distillations respectively at 55° C., 50° C., and 45° C., and subsequent treatment with strong sulphuric acid and caustic soda. The vapour of pentane is 2·5 times heavier than atmospheric air, and is as inflammable as ether. The specification for its preparation and testing is given in the Gas Referee's Notification for 1901, as follows :—

"*Preparation*.—Light American petroleum, such as known as Gasoline and used for making air-gas, is to be further rectified by three distillations, at 55° C., 50° C., and 45° C. in succession. The distillate at 45° C. is to be shaken up from time to time during two periods of not less than three hours each with one-tenth its bulk of—

(1) Strong sulphuric acid.
(2) Solution of caustic soda.

After this treatment it is to be again distilled, and that portion is to be collected for use which comes over between the temperatures of 25° C. and 40° C. It will consist chiefly of pentane, together with small quantities of lower and higher homologues, whose presence does not affect the light of the lamp.

"*Testing*.—The density of the liquid pentane at 15° C. should not be less than 0·6235, nor more than 0·626 as compared with that of water of maximum density. The density of the pentane when gaseous, as compared with that of hydrogen at the same temperature and under the same pressure, may be taken. This is done most readily and exactly by Guy Lussac's method, under a pressure of about half an atmosphere and at temperatures between 25° C. and 35° C. The density of gaseous pentane should lie between 36 and 38.

"Any admixture with pentane of hydrocarbons belonging to other groups

[1] See *Proc. British Assoc.*, Bristol, 1898, "On a 10-candle Lamp to be used as a Standard of Light," by A. G. Vernon Harcourt, F.R.S.

and having a higher photogenic value, such as benzene or amylene, must be avoided. Their presence may be detected by the following test: Bring into a stoppered 4-oz. bottle of white glass 10 c.c. of nitric acid, specific gravity 1·32 (made by diluting pure nitric acid with half its bulk of water), add 1 c.c. of a dilute solution of potassium permanganate containing 0·1 gram of permanganate in 200 c.c. Pour into the bottle 50 c.c. of the sample of pentane, and shake strongly during five successive periods of 20 seconds. If no hydrocarbons other than paraffins are present, the pink colour, though somewhat paler, will still be distinct; if there is an admixture of as much as ½ per cent. of amylene or benzene, the colour will have disappeared."

It is important to notice these precautions as to testing cannot be dispensed with. Merely to write to a wholesale chemist for pentane, or something called pentane, and then use it in a Harcourt lamp will not result in the reproduction of the standard of light. The pentane used in gas-testing is prepared in bulk by the Gas Companies, and is then tested by the Referees and supplied in sealed cans to the Gas-Testing Stations, which are under the control of Dr. F. Clowes, the Chemical Adviser of the London County Council, and Prof. Vivian B. Lewes, the Gas Examiner for the City Corporation.[1]

Mr. Vernon Harcourt has devised at various times five forms of lamp for burning pentane, three of them being 1-candle-power standards, and two of them 10-candle-power standards. The most important at the present time is the 1-candle-power standard which was introduced by him to the British Association at Plymouth in 1877.[2] The burner of this lamp consists of a brass tube 4 inches long and 1 inch in diameter, having a brass plug half an inch thick at the top, with a hole bored in it a quarter of an inch in diameter. Round the burner is placed a glass chimney 6 inches high and 2 inches in diameter, the top of which is level with the top of the burner. Air enters through holes in the gallery on which the chimney stands, and rises up round the flame. A piece of platinum wire 0·6 mm. in diameter is supported by a bracket 63·5 mm. above the top of the burner. The combustible used with this burner is a mixture of pentane vapour and air in the proportion of 3 cubic inches of pentane to 1 cubic foot of air. This mixture is made in a gas-holder in the proportion of 9 cubic inches of pentane and 3 cubic feet of air, and after standing should have a volume at a barometric pressure of 30 inches, and a temperature of 62° F. of 4 cubic feet, or more exactly between 4·02 and 4·1 cubic feet. This mixture is burned in the above jet at the rate of half a cubic foot per hour, or at a rate not exceeding the limits of 0·48 and 0·52 cubic foot per hour. The air-gas passes through a small meter and governor on the way to the jet. The height of the flame is regulated by a delicate stopcock to be 2·5 inches high, or just to touch the platinum wire.

[1] Mr. Vernon Harcourt has informed the author that this Standard Pentane can be procured from Mr. S. E. Miller, of 115, Cowley Road, Oxford, who has had experience under Mr. Harcourt's direction in making it. Messrs. Wright & Co., of Precision Works, Page Street, Westminster, who supply the latest form of 10-candle Pentane Lamp, have also undertaken to put on sale standardized pentane complying with the above specification.

[2] See *Proc. Brit. Assoc.*, Plymouth, 1877, p. 51. See also *Proc. Brit. Assoc.*, Southport, 1883, p. 426; and *Proc. Brit. Assoc.*, Bristol, 1898, p. 845.

This adjustment needs care, and in doing it the observer's eye should be screened from the general mass of the flame and see only the tip. When these operations are performed, we have a yellow-white flame produced which yields a light equal to the mean British Standard candle, but is much more constant. It need hardly be said that this Pentane lamp has to be used in a suitable position with good ventilation, but free from draughts, and there are certain corrections to be applied for variations in the atmospheric pressure and moisture and carbonic dioxide present in the air.

The effects of variations in the hygrometric state of the air and of barometric pressure on the Pentane flame have been investigated by Liebenthal and by Mr. Harcourt.[1] The latter states with reference to the 1-candle Pentane standard that the height of the cone of flame varies inversely as the barometric pressure, and he gives the following rule for the correction of standard heights of flame. The standard height of flame for which the emitted light is equal to one candle is 63·5 mm. at 30 inches barometric pressure, and for every tenth of an inch above or below 30 inches the flame must be set an equal number of fifths of a millimetre below or above 63·5 mm. Hence when the barometer stands at 30·5 inches, the height of flame to give one candle is 62·5 mm.

Liebenthal[2] examined the effect of water vapour on the Harcourt 1-candle lamp with wick, and found that its luminous intensity in terms of the Hefner unit (see below) was expressed by the formula :—

$$L = 1{\cdot}232\,(1 - 0{\cdot}0055\,w),$$

where w is the number of litres of water vapour in each cubic metre of dry air. The formula holds good between 4 and 18 litres.

Also he investigated the effect of atmospheric pressure, and states that the change in the illuminating power of the Pentane lamp is expressed by the rule :—

$$\Delta L = 0{\cdot}00049\,(H - 760),$$

where ΔL is the variation of light corresponding to a barometric height of H millimetres. Thus an increase of 40 mm. in pressure results in a variation of the light of 2 per cent.

These experiments were made with a form of portable 1-candle Pentane lamp which was brought out some time ago, and sometimes called the Woodhouse and Rawson pattern, from the names of a firm who sold it. The writer is not aware whether particular experiments have yet been made to determine the effect of variations of atmospheric pressure, carbon dioxide, and moisture upon the luminous intensity of the official 10-candle chimneyless Argand Pentane Lamp described above. It appears desirable, however, that this information should be obtained, in view of the adoption of the lamp as a standard by the Gas Referees.

It will not be necessary here to describe in great detail all the

[1] See *Proc. Brit. Assoc.*, Aberdeen, 1885.
[2] *Electrotechnische Zeitschrift*, vol. 3, p. 445, and vol. 5, p. 20.

operations of reproducing a standard of light with this Pentane lamp. These can be obtained from the numerous reports and descriptions of it which have already been given. After careful investigation, its use was recommended by a Committee of the Board of Trade in 1881, and by the Standards of Light Committee of the British Association in 1888. This last committee reported that the Pentane standard fulfilled all the conditions required in a standard of light. They found that the light was not altered by slight variations in the specific gravity of the pentane varying between 0·628 and 0·632. Out of 117 tests only one showed a variation of 1 per cent., and there were no larger variations. It has been demonstrated, therefore, that this standard affords a means of reproducing with an accuracy of 1 per cent. a light which represents fairly the ideal mean British standard candle. The necessity for employing the gas-holder, meter, governor, and other checking appliances renders this lamp more suitable for a primary reference standard than a working standard. These last objections, however, have been removed in the latest form of Harcourt Pentane Lamp, which is the one mentioned as now adopted by the Gas Referees. A full description of this lamp is given in the notification of the Gas Referees for 1901, Appendix A; and also in a paper by Dr. F. Clowes, Superintending Gas Examiner of the London County Council, in the *Journal of the Society of Chemical Industry*, March 15, 1902, No. 5, vol. 21.

This lamp, which is exhibited on the table before you, has a reservoir called *a saturator*, which contains pentane placed at the top of a hollow pillar. The reservoir has two openings closed by stopcocks, one to admit air and the other as an exit for pentane vapour. The pentane vapour descends through an india-rubber tube by its own weight, being syphoned off from the space above the liquid pentane in the reservoir. It is led down into an Argand burner at the base of the pillar. Over this is a double metallic chimney. The air supplied to the centre of the burner is drawn up between two concentric chimney tubes and led down the pillar to the burner, as shown in the diagram. Hence the arrangement forms a sort of regenerative burner. The chimney comes down to within a distance of 47 mm. above the steatite ring burner, the proper gap being determined by a boxwood gauge. The chimney cuts off the top of the flame, and there is a mica window in the chimney through which to observe the height of the tip of the flame. The flame is moreover surrounded by a conical metallic shield with an opening in it. This lamp is managed with great ease. All that is necessary is to put into the reservoir a pint of pentane, and then to open both stopcocks and after a few moments to light the jet of vapour at the burner, and regulate flow of air and vapour by the stopcocks until the tip of the flame is seen at the middle of the mica window. When so adjusted, the lamp gives a light ten times that of the 1-candle Pentane Standard, and is taken as the official standard of 10-candle light by the Gas Referees. It is necessary to adjust the height of the flame somewhat exactly, and to wait for the lamp to settle down to an uniform temperature before beginning observations.

The following is the official description of the lamp given by the Gas Referees in their notification for November, 1901 :—

"Mr. Harcourt's Ten-Candle Pentane Lamp is one in which air is saturated with pentane vapour, the air-gas so formed descending by its gravity to a steatite ring-burner. The flame is drawn into a definite form, and the top of it is hidden from view by a long brass chimney above the steatite burner. The

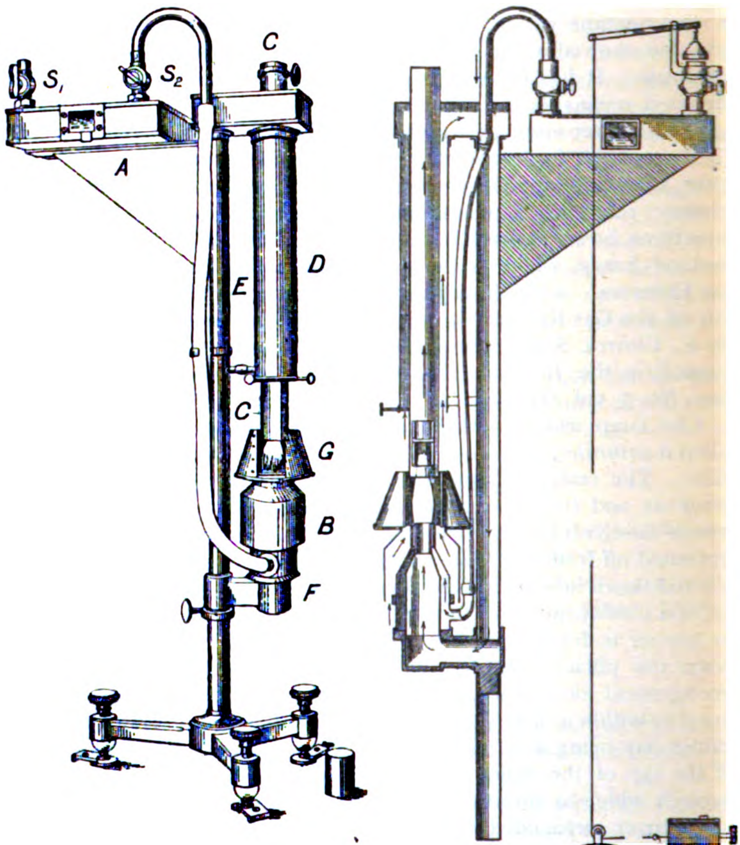


FIG. 1.—VERNON HARCOURT PENTANE TEN-CANDLE LAMP.[1]

chimney is surrounded by a larger brass tube, in which the air is warmed by the chimney, and so tends to rise. This makes a current which, descending through another tube, supplies air to the centre of the steatite ring. No glass chimney is required, and no exterior means have to be employed to drive the pentane vapour through the burner.

[1] The author is indebted for permission to make use of the block of Fig. 1 to the editor of the *Journal of Gas Lighting*, and acknowledgment is here gladly rendered for the courtesy.

"Fig. 1 shows the general appearance of the lamp. The saturator *A* is at starting about two-thirds full with pentane. It should be replenished from time to time, so that the height of liquid as seen against the windows may not fall below one-eighth of an inch. The saturator *A* is connected with the burner *B* by means of a piece of wide india-rubber tube. The rate of flow of the gas can be regulated by the stopcock S_2, or by checking the ingress of air at S_1. For this latter purpose, a metal cone, acting as a damper, is suspended by its apex from one end of a lever to the other end of which is attached a thread for moving the cone up or down. The lever is supported by an upright arm clamped to the upper end of the stopcock immediately beneath the cone. From the top of the lamp the thread descends to a small pulley on the table, and thence passes horizontally to the end of a screw moving in a small block, by turning which the gas examiner can regulate the lamp without leaving his seat. It is best so to turn the stopcock S_2 as to allow the flame to be definitely too high, but not to turn it full on before letting down the regulating cone to its working position. Both stopcocks should be turned off when the lamp is not alight.

"The chimney tube *C C* should be turned so that no light passing through the mica window near its base can fall upon the photoped. The lower end of this tube should, when the lamp is cold, be set 47 millimetres above the steatite ring-burner. A cylindrical boxwood gauge, 47 millimetres in length and 32 in diameter, is provided with the lamp to facilitate this adjustment. The exterior tube *D* communicates with the interior of the ring-burner by means of the connecting box above the tube *E*, and the bracket *F*, on which the burner *B* is supported (see sectional diagram, Fig. 1). A conical shade *G* is provided. This should be placed so that the whole surface of the flame beneath the tube *C* may be seen at the photoped through the opening.

"The lamp should be adjusted by its levelling screws so that the tube *E*, as tested with a plumb-line, is vertical, and so that the upper surface of the steatite burner is 353 millimetres from the table. A gauge is provided to facilitate this latter measurement. The tube *C* is brought centrally over the burner by means of the three adjusting screws at the base of the tube *D*. This adjustment is facilitated by means of the boxwood gauge.

"When the lamp is in use, the stopcocks are to be regulated so that the tip of the flame is about halfway between the bottom of the mica window and the cross-bar. A variation of a quarter of an inch either way has no material influence upon the light of the flame. The saturator *A* should be placed upon the bracket as far from the central column as the stop at the end will allow. If it is found, after the lamp has been lighted for a quarter of an hour, that the tendency of the flame is to become lower, the saturator may be placed a little nearer the central column.

"To prevent a gradual accumulation of dust in either the burner or the air-passage, a small cover of the size of the top of *B* and shaped like the lid of a pill box, should be kept upon the lamp when not in use."

This latest pattern of self-contained Pentane lamp is altogether superior as a standard to the 1-candle-power Pentane lamp with a wick, which was brought out some years ago to meet the requirements of a working standard.

For comparison with glow-lamps, a 10 c.p. standard is a more convenient unit than 1 c.p., and moreover, the earlier form of 1 c.p. lamp with a wick was more trouble to start in action and had other defects, which are absent in the 10 c.p. standard.

An important point in connection with this 10-candle Standard is that it requires and has no glass chimney. Other Pentane lamps have been produced in which a glass chimney is employed, but this feature always introduces an element of uncertainty into the working of any standard of light. Moreover, the light from the top of the flame is cut off by the metal chimney, and this probably contributes to prevent the light emitted being influenced by normal variations of atmospheric pressure so much as is the case with open flame lamps. The light is, however, affected by the presence of water vapour and carbon dioxide in the air, as in the case of all other flame standards.

The third flame standard, which has come into very general use, and is especially popular in Germany, no doubt on account of its German origin, is the so-called Hefner Lamp, which was introduced by Herr von Hefner-Alteneck in 1884.[1] This well-known lamp consists of a small metal body containing the combustible, and from out of it a metal tube made of German silver, containing the wick, rises. The tube is 8 mm. inside diameter, and 8·3 mm. outside diameter, and 25 mm. high. The wick is formed of strands of cotton yarn. Separate threads to the number of 15 or 20 are laid together straight, not twisted, until the size of wick is sufficient to fill up the tube without squeezing. The exact number of strands is not of great consequence, and only affects the height of the flame. By means of a simple rack mechanism the wick is moved up and down so as to alter the flame height, and by means of a small rod fixed at the top of the lamp carrying two metal sights, the flame can be adjusted to be exactly of the standard height of 40 mm.

The material burned in the lamp is Amyl Acetate $C_7H_{14}O_2$. The quantity of the combustible in the lamp does not matter as long as all the lower ends of the wick are well immersed. The wick should be trimmed square at the top of the tube, and after filling the lamp it should be allowed to burn ten minutes before adjusting the flame and making the measurement.

It was claimed by the inventor that the absolute purity of the Amyl Acetate was not of very great importance; but this has been lately denied, others asserting that it is essential to use chemically pure Amyl Acetate.

The lamp is used without a chimney, and as the flame is very lambent or mobile, it must be carefully protected from draughts. The luminous intensity of this flame is less than that of a British Standard candle. Measures of the ratio, however, made by different observers do not agree very well. Table I. (p. 129) is taken from a preliminary report of a Sub-committee of the American Institute of Electrical Engineers on Standards of Light, issued in 1896.[2]

The variation in the value of the ratio is partly due to the uncertain value of the British Parliamentary Candle, and partly to personal errors, but also to the different methods of comparison adopted, affecting the ratio in consequence of the difference in the quality of the two lights

[1] *Elektrotechnische Zeitschrift*, vol. 3, p. 445, and vol. 5, p. 20.
[2] See *Transactions of the Amer. Inst. of Elec. Eng.*, vol. 13, 1896.

TABLE I.

Observer.	Ratio of the Hefner Unit to the British Candle.
SHARP. From observations against Standard Candles reduced for rate of burning	0·872
SHARP. From observations against Standard Candles reduced for flame height	0·892
SHARP AND TURNBULL. From observations with the bolometer and candles	0·98
VIOLLE	0·98
REICHSANSTALT INVESTIGATIONS. Mean value	0·876
NETHERLAND PHOTOMETRY COMMISSION	0·921
S. SCHIELE. Mean value	0·881

compared. The most probable value appears to be 0·88.[1] Hence we may reasonably assume that luminous intensities expressed in Hefner units have to be multiplied by 0·88 to reduce them to their equivalent in British Standard Candles.

The chief objection that has always been raised (in countries other than Germany) to the use of the Hefner Lamp as a standard, is the reddish character of the light. In this respect it compares very unfavourably with the Harcourt 10-candle Pentane Lamp, the light of which is comparable in quality with that of a glow-lamp working at about 3 watts per candle-power. In other words, the Pentane flame is at a temperature nearer to that of the glow-lamp filament when in use. The employment of the Hefner Lamp as a means of standardising glow lamps when used at the ordinary efficiencies, gives rise to the difficulties of heterochromatic photometry, to which allusion will be made presently. Its use in arc-lamp photometry is out of the question. This lamp has been very carefully investigated by Liebenthal.[2] He studied the effect of water vapour, and carbon dioxide in the atmosphere, on the luminous intensity of the lamp. If w represents the volume of water vapour in litres per cubic metre of dry air, then the light (L) of the Hefner Lamp is expressed by the following linear function :—

$$L = 1·049\,(1 - 0·0053\,w).$$

The formula holds good between 3 and 18 litres of water vapour per cubic metre. The light of the Hefner Lamp decreases, therefore, about 0·5 per cent. per litre of water vapour, and has a value equal to unity, when 8·8 litres of water vapour per cubic metre of dry air are present in the atmosphere, according to the regulations of the Berlin Reichsanstalt.

Taking the average variations of moisture in the air from month to month, we find that this implies a variation of about 4 per cent. in the light between the wet and dry seasons of the year.

Again, if c represents the quantity of carbon dioxide present in the

[1] This is the value taken in a Specification for the supply of Glow Lamps, issued by the General Post Office. (See a paper by Sir W. H. Preece, F.R.S., on "Electric Glow-Lamp Tests," *Proc. Brit. Assoc.*, Liverpool, 1896, or *Electrician*, vol. 37, p. 738, 1896.)

[2] *Physical Society Abstracts*, vol. 1, abs. 501 ; *Elektrotechnische Zeitschrift*, 1895, vol. 16, p. 655 ; also *Zeitschrift für Instrumentenk.*, vol. 15, p. 157, 1895.

atmosphere in litres per cubic metre, then the luminous intensity L is expressed by the following formula :—

$$L = 1{\cdot}012\,(1 - 0{\cdot}0071\,c).$$

Also slight variations in the height of the flame have a great influence on the luminous intensity. If h is the height of the flame in millimetres, then the luminous intensity L is expressed by the following linear functions :—

$$L = (1 + 0{\cdot}025\,(h - 40)),$$
$$L = (1 - 0{\cdot}030\,(40 - h)),$$

according as h is above or below 40 mm. A change of 1 mm. in the height of the flame creates, therefore, a 3 per cent. change in the light.

Finally, variations in atmospheric pressure affect the light given by the lamp. Between 735 mm. and 775 mm. barometric pressure the light variation may be expressed by the following formula :—

$$\Delta L = 0{\cdot}00011\,(H - 760).$$

Where Δ L is the change in the value of the light, corresponding to a barometric height of H mm. This represents a variation of 0·1 per cent. for 10 mm.

Unless all these corrections are applied, the luminous intensity of the Hefner Lamp is uncertain within limits greater than those which can easily be determined photometrically.

The effect of carbon dioxide in the atmosphere on the luminosity is important. A change of 1 litre per cubic metre of air—that is to say, a variation of 1 part in 1,000—affects the intensity of the light 0·7 per cent. Hence it is quite clear that in badly ventilated rooms or rooms where many people are gathered together, carbon dioxide will be present to an extent which materially influences the light of the lamp.[1]

Turning, then, next to the subject of Incandescence Standards of Light, we may say that the only practical standards of this description which have been evolved, are those in which either platinum or carbon heated to a high temperature is employed. The platinum standard, suggested by M. Violle, was adopted as an International Standard at the Paris Congress of Electricians in 1884. M. Violle proposed in 1881 to define the unit of light as the light radiated normally from one square centimetre of platinum at its melting-point. The International Congress of Electricians in 1889 adopted the proposal that the practical unit of light should be one-twentieth part of the Violle Platinum unit. This sub-division was called the *bougie decimale*, this last term being the name for the tenth part of the carcel; the platinum unit having been found by M. Violle to be nearly equal to two carcels. Objections have been raised to the platinum unit on several grounds. In the first place, a very large mass of expensive metal is necessary, and the prac-

[1] For a series of curves showing the variation of the Hefner Lamp with barometric pressure and moisture, see the *Electrical Review*, vol. 42, p. 759, 1898.

tical difficulties in carrying out the photometric comparison with secondary standards were found to be considerable. An attempt was made at the Reichsanstalt in Berlin to reproduce the Violle Standard. but apparently with no very great success, and the British Association Committee on the Standards of Light in their Report, presented in 1888, stated that they consider that this standard was not a practical standard of light, although they were prepared to accept it as the definition of a unit. The meaning of this decision is not very clear. Since that date, however, a long research has been carried on at the Davy-Faraday Laboratory in 1899 by Mr. J. E. Petavel, who made the Violle unit the subject of a careful investigation.[1] The first operation is to melt a large mass of pure platinum, by means of the oxy-hydrogen blow-pipe, in a lime crucible. Mr. Petavel came to the conclusion that the essential conditions of success for the reproduction, by the use of molten platinum, of a constant standard of light are that :—

1. The platinum must be chemically pure.
2. The mass of it should not be less than 500 grams.
3. The crucible must be made of pure lime.
4. The hydrogen burned must contain no hydrocarbons.
5. The gases should be burned in the ratio of 4 volumes of hydrogen to 3 of oxygen.

The process of producing the unit of luminous intensity by the platinum standard consists in melting this mass of platinum under the above conditions. A water-cooled diaphragm screen is then placed over the molten metal, having in it an aperture one square centimetre in area. The light from the molten platinum is reflected to a photometer by a mirror, and the metal is then allowed to solidify. The temperature of the metal falls to the freezing point, and then remains practically constant until the solidification is completed. During this time of constant temperature, the light emitted from the selected area is also practically constant. Full details of the operations are given in Mr. Petavel's paper.

His inference from the whole of his work is that when carried out with the stated precautions, the probable variation in the light emitted by molten platinum under the standard conditions is not above 1 per cent., and he considers that with more perfect apparatus and with certain improvements the accuracy of this standard would be increased.

This investigation, therefore, seems to have rescued the Platinum Standard from some undeserved condemnation. In a similar manner, the platinum resistance-thermometer was at first underrated in value, until it was restored by Professor Callendar to its present position of utility. We have grounds, therefore, for the belief that the Platinum Standard in some perfected form may yet prove to be the best ultimate standard of luminous intensity. Apart from the not insuperable difficulties of its employment, it realises in a very perfect form the condi-

[1] See *Proc. Roy. Soc.*, vol. 65, p. 649. J. E. Petavel, "An Experimental Research on some Standards of Light."

tions which are necessary for such a standard, namely, a perfectly pure material maintained at an absolutely constant temperature in a definite condition, the luminous radiation from a unit of area of it then constituting the unit of luminous intensity. The Violle Platinum standard has the additional recommendation that it is not only a unit of light but also a unit of brightness. It is, however, a standard of such a nature that it is not likely to be set up anywhere except at the National Physical Laboratory. It is unnecessary to recapitulate here all the details of the various attempts that have been made to replace the Violle Platinum Standard and obtain an Incandescent Platinum Standard which could be more easily employed as a Working Standard. The most promising of these seemed at one time to be the method suggested by Lummer and Kurlbaum.[1] Briefly, their mode of defining the unit of luminous intensity was as follows :—

It was to be the light emitted from a square centimetre of solid platinum when brought by an electric current to such a temperature that 10 per cent. of its radiation, as measured by a bolometer, could pass through a layer of water two centimetres in thickness contained in a cell with quartz sides. For the details of this experiment the original paper may be consulted. The apparatus was established in the Reichsanstalt at Berlin, and is used at present as a standard of reference for Hefner Lamps.[2]

The only attempt to repeat this work in England has been (so the writer believes) made by Mr. J. E. Petavel, who set up the apparatus in the Davy-Faraday Laboratory (see *Proc. Roy. Soc.*, vol. 65, p. 478). His conclusion, however, was that the adjustments were very difficult, and in addition the spectral quality of the light not satisfactory as a standard, being much less white than that of the Violle Platinum Standard. Hence he gives it as his opinion that the Lummer-Kurlbaum Standard, in spite of the preference shown for it in Berlin, does not possess the qualities required in a primary Standard of Light.

The consideration of the possibility of using carbon filament lamps as standards of light has been very much before the mind of the author during the eighteen years that he has acted as Scientific Adviser to the Edison and Swan United Electric Light Company, Limited.

The difficulties with flame standards which arise from variations in atmospheric pressure and moisture, and from the contamination of the air in badly ventilated rooms by carbon dioxide, rendered it desirable to endeavour to devise a simple working standard which is independent of atmospheric composition. Hence, many years ago the writer's attention was called to the question of the use of the electric glow-lamp as a standard of luminous intensity.

The first objection that of course arises is that the decay in light-giving power of an ordinary carbon filament lamp, even when worked at a moderate efficiency, renders it perfectly valueless as a standard. A carbon filament lamp alters in light-giving power when used at constant voltage, for three reasons, viz., by—

[1] Lummer and Kurlbaum, *Elektrotechnische Zeitschrift*, vol. 20 (1894), p. 474.
[2] *The Reichsanstalt Unit of Light*, by Lummer and Kurlbaum, *Electrician*, vol. 34, p. 37 and p. 77.

(1) Changes in electric resistance of the filament.
(2) Changes in the nature of the surface of the filament.
(3) The deposit of carbon upon the interior of the bulb.

It is well known that the candle-power of new glow-lamps of the majority of types increases for a short time after they have been put into use. This is due to a decrease in the resistance of the filament. The filament becomes more consolidated and probably denser, and therefore decreases in resistance. If, however, a good filament is run in a lamp at normal, or slightly above normal, voltage for fifty

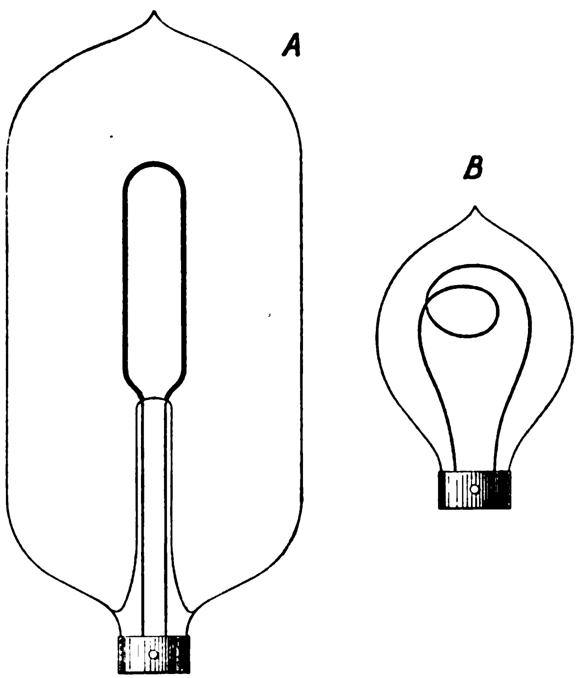


FIG. 2.

A. FLEMING-EDISWAN STANDARD GLOW-LAMP.
B. ORDINARY EDISWAN 16-C.P. GLOW-LAMP.

hours or so, it reaches a condition in which a small further use will not much alter it. By that time, however, the glass bulb is somewhat blackened, and the lamp will have lost candle-power. Experiments made by the writer several years ago, showed, however, that if a filament which has been so "aged" is removed from the old bulb, and put into a new clean bulb, the candle-power will again be brought back to a value not far from its original value. It therefore occurred to the writer to prevent the blackening of a glow-lamp by the following means: The blackening is caused by the projection of carbon from the

filament, and hence other things being equal proceeds most rapidly in small bulbs, because the carbon molecules then most easily reach the glass. Suppose, however, that a filament is mounted in a very large bulb, the radius of which is much greater than the mean free path of the molecules at the pressure of the residual air. The chances of a molecule of carbon getting on to the glass are much reduced. Accordingly, about six years ago, the author requested Mr. E. Gimingham, Superintendent of the Edison and Swan Electric Light Factory, to mount some 16-c.p. filaments in very large bulbs, and it was found that these lamps could be run for long periods without any of the usual blackening or loss of light. This observation led, therefore, to the following method of constructing a special form of carbon filament lamp to be used as a standard of light. Carbon filaments of the old Edison horseshoe shape are well selected and carefully treated, and are then mounted in ordinary bulbs, and run as lamps for some time, at about 5 per cent. above marked voltage for about fifty hours. Those filaments which then show no defects are cut out of these slightly blackened bulbs and mounted in very large clear glass bulbs, 6 or 8 inches in diameter. These lamps, if not very much used, and not worked above a certain marked voltage, will remain practically constant for any length of time.

In 1896 a good many experiments were made on this plan at the Edison and Swan Lamp Factory.[1] A number of these large bulb lamps were prepared, and carefully photometered against a pentane air-gas standard as giving us the best means of fixing at that time a standard equal to 10 British Standard candles. The working voltage of the lamps was carefully measured by means of a potentiometer and a Clark cell, and the candle-power, voltage, and current recorded on each lamp, the candle-power taken being that in a horizontal direction and perpendicular to the plane of the filament when the axis of the filament was vertical. A certain number of these lamps were set on one side, and called Primary Standards, with the intention that they should be used only very occasionally for verifying the candle-power of others of the lamps, which were called Working, or Secondary Standards. These secondary standards were to be employed to set the working lamps in the various photometer rooms.

A similar set of primary and secondary lamps of this description was made for the Pender Laboratory, University College, London. These lamps have been in use for several years in the Edison and Swan Company's Factory at Ponder's End, and at the Pender Laboratory, and have been found to be very convenient. In the month of March, 1902, with the kind co-operation of Mr. E. Gimingham, some experimants were made at the Edison-Swan Factory, Ponder's End, to ascertain how far any difference might have arisen in six years between

[1] The author desires to take this opportunity of gratefully acknowledging the kind encouragement and valuable support he has continually received from Mr. J. W. Swan, F.R.S., in this and many other similar investigations during the whole period of his connection as Scientific Adviser with the Edison and Swan United Electric Light Company, Limited. In addition, the author has pleasure in referring to the assistance rendered by Mr. E. Gimingham in working out this form of Standard Ediswan Glow Lamp.

the Pentane air-gas standard used there, and certain of these standard carbon filament lamps. The lamps were accordingly checked in a photometer room, using a Lummer-Brodhun photometer to measure the light, and a Crompton potentiometer and Clark cell to measure the current and voltage. In order to eliminate the personal error, three or more observers were admitted to the photometric gallery. This somewhat unusual proceeding, however, and the want of attention on one occasion to the ventilation, resulted in revealing an apparent discrepancy between the candle-power of the lamps as measured in terms of the Pentane flame in 1896, and those made in March, 1902.[1] The following table shows the results of these first observations, the three observers being denoted by the figures (i.), (ii.), and (iii.) :—

TABLE II.

COMPARISONS BETWEEN THE PENTANE AIR-GAS STANDARD AND LARGE BULB STANDARD INCANDESCENCE ELECTRIC LAMPS.

Readings taken March 8, 1902, *at the Edison-Swan Factory, Ponder's End*

Mark on Standard Glow Lamp.	Working Volts on Lamp.	Candle-power by Pentane Standard read by Three Observers.				Candle-power of Glow Lamp as determined previously.
		(i.)	(ii.)	(iii.)	Mean c.p.	
Ediswan R_2 ...	99·1	14·6	14·4	—	14·5	14·0 in Feb., 1902
Ediswan S_4 ...	96·2	10·4	—	10·4	10·4	10·0 in 1896
Ediswan S_3 ...	96·1	10·4	10·6	10·6	10·5	10·0 in Jan., 1902
Pender I..........	96·0	14·8	14·6	—	14·7	14·3 in 1896
Pender II.	96·0	16·9	16·8	16·5	16·7	16·4 in 1896
Pender III.......	96·0	14·5	14·2	14·2	14·3	
Test repeated...	"	13·75	13·75	—	13·75	12·75 in 1896
Ditto	"	14·0	13·9	—	13·95	

If we were entitled to take for granted that the Pentane Standard had remained unaltered, the above table would seem to show a falling off in the candle-power of the glow-lamps in the six years. This, however, is not a valid conclusion. The greater difference between the 1896 and 1902 measurements in the case of the lamp Pender Standard III. showed that probably all was not right on this occasion with the Pentane lamp. This, in fact, was the case. The presence of an unusual number of persons (four) in the photometer room vitiated the air towards the end of the time of observations. The doors were therefore all thrown open for forty minutes, and after the air in the room had been thoroughly renewed the measurements were repeated as below:—

[1] The observations in 1896 were made with great care by Mr. J. T Morris, at one time private assistant to the author, but now Lecturer on Electrical Engineering in the East London Technical College. The observations in 1902 were made under the direction of Mr. W. C. Clinton, B.Sc., Demonstrator in the Pender Laboratory, and to whom the author is indebted for valued and willing assistance in the experiments here described, as well as many others related to this investigation.

TABLE III.

Second Set of Readings taken with Photometer Room well ventilated.

Mark on Standard Glow Lamp.	Working Volts on Lamp.	Candle-power by Pentane Standard read by Three Observers.				Candle-power of Glow Lamp as determined previously.
		(i.)	(ii.)	(iii.)	Mean c.p.	
Pender I.	96·0	14·4	14·25	14·0	14·22	14·25 in 1896
Pender II.	96·0	16·5	16·7	16·0	16·4	16·4 in 1896
Pender III.......	96·0	12·75	13·0	12·5	12·75	12·75 in 1896
Pender IV.......	96·0	14·1	–	13·9	14·0	14·5 in 1896
Pender V.	96·0	15·5	15·25	15·0	15·4	15·55 in 1896
Pender VI.......	96·0	11·9	11·7	11·65	11·75	11·5 in 1896
Ediswan S_4 ...	96·2	10·1	9·8	9·8	9·81	10·0 in 1901
Repeated......	,,	9·7	9·65	9·8		

During these tests the temperature of the Clark cell rose from 16° C. to 20° C. This alone would imply a possible error in voltage of 0·36 per cent., and an uncertainty therefore in candle-power of 1·8 per cent. The results of the measurement are, however, to show that in six years, during which these glow-lamp standards have been much used, the set belonging to the Pender Laboratory have probably remained as constant in light-giving power at the same voltage as the Pentane Standard. Since a standard glow-lamp of this form, used as described in the next section of the paper, is only in a state of incandescence for a few minutes at a time during each test, the use of such a lamp in many hundreds of tests only amounts in all to a few hours' burning. It is clear, therefore, that if the filament has been brought into a condition in which it has passed the initial variable stage during which changes may take place in it, and if after that time it is only used for exceedingly short periods of time, and in a large bulb as described, it becomes a means of preserving a standard of light with great constancy.

The differences in the figures in the above Table III. between the lamp Pender IV. and Ediswan S_4, and Pender IV. and the Pentane Standard, must not be attributed wholly to changes in the standard glow-lamp. In the case of the test made with the standard lamp Pender IV. it will be seen that the candle-powers were only read by two out of the three observers. With this exception, none of the lamps which have been in use in the Pender Laboratory for six years now appeared to differ from the Pentane Standard by more than 2 per cent., and in the majority of cases there is no sensible difference, and, as observed above, the whole of this difference, where it appears, must not be set down to changes in the incandescent lamp. In fact, these large bulb glow-lamp standards were easily able to detect a temporary variation in the Pentane Standard due to inattention to the ventilation of the room.

This error was not small. At the end of the first set of tests the atmosphere had become vitiated to such a degree that, partly for this reason and partly perhaps from errors in adjustment of flame

height, the flame standard had fallen off in illuminating power by 8 to 10 per cent., and hence made an incandescent lamp of which the real candle-power was 12·75 appear to be about 14·3. The operation was not, in fact, a test of the incandescence lamps by the Pentane, but a test of the latter by the former.

The experience, however, gained by the writer in the last six years, and also at the Edison Swan Lamp Factory, justifies the expression of opinion that these large bulb standard carbon filament lamps form a very convenient and accurate means of preserving a standard of light when proper precautions are taken to set them to a marked voltage by means of a potentiometer and Clark or Weston standard cell.

One other suggested incandescence standard must be briefly mentioned. It was proposed by Mr. Swinburne, Professor S. P. Thompson, M. Blondel, and others, that the light from one square millimetre of the crater of the arc-lamp should be taken as a standard of luminous intensity. Measurements of the intrinsic brilliancy of the crater by different observers do not agree very well, and it cannot be said that the experimental work done so far holds out a promise that this source of light will fulfil all the requirements of a standard.

Measurements of the intrinsic brightness of the arc crater made by Mr. Trotter, M. Blondel (in 1893), and Mr. Petavel (in 1900) gave values for this constant respectively of 170, 158, and 147 candles per square millimetre. The actual incandescent area which forms the crater is, however, very small, and, according to a discovery made by Mr. Trotter it very often exhibits a rapid rotatory movement, so that it is not so simple, physically speaking, as a surface of molten platinum. The intrinsic brilliancy of the crater is so great, and the quality of its light is so different from that of most secondary standards, that it is a matter of greater difficulty to compare this arc standard with a secondary standard than is the case with the Violle Platinum Standard. Hence for all these reasons an incandescent platinum standard will probably be preferred.

The conclusion, therefore, which may be drawn from the preceding facts is that at the present moment there are five sources of light which can in all probability be regarded as sufficiently constant to enable them to be used for reproducing a standard of luminous intensity with a degree of accuracy approximating to 1 per cent. or less. Two of these may be called primary or reference standards, and three working standards. The Primary Standards are :—

1. The Violle Platinum Incandescent Standard.
2. The Vernon-Harcourt Pentane 1-candle Flame Standard ;

and as practical Working Standards :—

3. The Hefner or Amyl Acetate Lamp.
4. The Vernon-Harcourt Self-contained 10-candle Pentane Lamp.
5. The Fleming-Ediswan Large Bulb Incandescence Electric Lamps.

The first two Reference Standards can be set up at a National Standardising Laboratory, or a Government Testing Laboratory, and

can be relied upon to preserve a selected standard or unit of light with an accuracy which is comparable with that of photometric measurements generally.

Of the three Working Standards, the Amyl Acetate Lamp is decidedly inferior to the other two in the quality of its light, and difficulties arise in using it even to standardise glow-lamps, whilst it is quite unsuitable for use with arc-lamps. Moreover, experience shows that a 1-candle standard is not so generally useful as a 10-candle.

One objection which has been raised to the employment of the Violle standard as a primary standard is that it involves the use of a mirror to reflect the vertical ray from the molten platinum into the photometer, being used to compare it with a secondary flame standard, and hence there is possibility of error produced by the slight uncertainty attaching to the co-efficient of the reflection of the mirror. The defect could be obviated by employing a photometer placed vertically over the molten platinum to compare the emitted light from it with a large bulb glow-lamp standard made on the author's plan, and this again could be compared with any required flame standard, the ray from which must necessarily be horizontal.

Other objections have been raised to the employment of the Violle standard as a practical primary reference standard, such as the difficulties likely to arise from the column of hot air ascending from the platinum.[1] A further investigation of this standard is therefore much to be desired, and it seems a piece of work that might very suitably be undertaken in the National Physical Laboratory, where it is to be hoped a Primary Reference Standard of light may before long be established.

II. Photometric Processes.

It would cause the present paper to greatly exceed reasonable limits in length, if any attempt were made to discuss the whole of the photometric processes which have been devised. It is certainly not necessary to repeat here information which can be obtained from ordinary treatises on photometry. Generally speaking, a photometric measurement consists in comparing together the brightness of two white surfaces, one illuminated solely by the light under test, and the other by a standard light, and adjusting the distance of the lights until an equality in brightness or illumination is secured. A typical and simple form of photometer, therefore, is the Ritchie wedge, in which two adjacent sides of a white prism inclined at equal angles to the incident rays serve as the two surfaces which are differently illuminated. Whatever may be the exact nature of the arrangement for creating these two contiguous surfaces illuminated by different sources of light, it appears to be an essential condition for sensitiveness that they shall not be separated by any dark or bright space not illuminated wholly by one light or the other. Thus, for instance, the accuracy with which measurements can be made by the Ritchie wedge is greatly decreased

[1] This source of error was suggested to the author in conversation by Mr. A. G. Vernon Harcourt.

if the edge of the wedge is blunt. If the eye has to travel far in going from one surface to the other, then the power to make a correct judgment as to the equality in the brightness of the two surfaces is greatly diminished. Hence, whatever form a photometer may take, it must be in one in which this accurate juxtaposition of the two surfaces to be compared can be secured. Another condition is, that the illuminated surfaces must be perfectly white. There is a vast difference between surfaces in regard to whiteness, which are all called white. Paper, cardboard, and newly fallen snow, look very different when illuminated by the same source of light under the same circumstances. A suitable white surface for photometry can be obtained by compressing magnesium carbonate or barium sulphate into slabs. In the Lummer-Brodhun

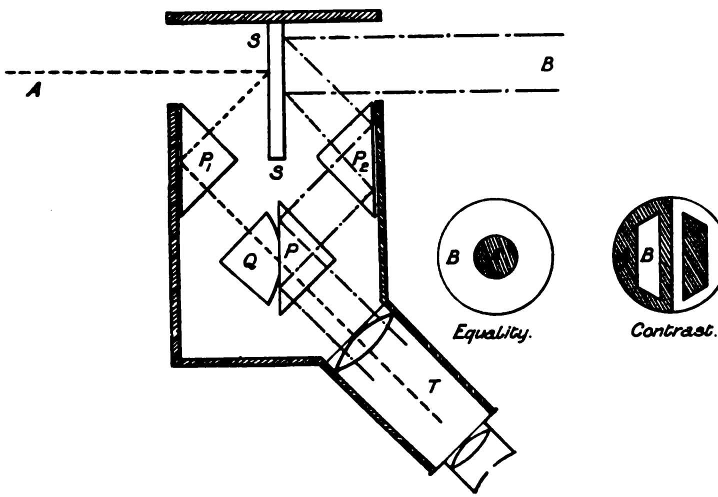


FIG. 3.—LUMMER-BRODHUN PHOTOMETER.

S. Magnesia Screen. P_1 P_2. Totally reflecting Prisms.
Q P. Lummer-Brodhun Prism. T. Telescope.

photometer, such a white magnesia slab is illuminated on its two opposite sides by the two lights to be compared (see Fig. 3). By the means of two totally reflecting prisms, P_1, P_2, the diffused light from the two sides is sent through a compound glass prism, P Q, consisting of two right-angle prisms placed base to base. One of these prisms has portions of its hypothenuse surface removed by sand-blasting, so as to be at a lower level than the rest, and the two right-angle prisms have their hypothenuse surfaces placed together, being faced to come into optical contact where they touch.

When such a prism is viewed by means of a telescope and an eyepiece in the proper position, we see the field of view divided into two parts, one portion of which is illuminated by the diffused light scattered from one side of the magnesia slab, and the other side by light scattered from the other. By adjusting the distances of the lights,

the brightness of these two portions of the field of view can be made to agree. If the lights are heterochromatic, then these two portions of the field of view have different colours as well as different brightness. and the observer has to make a judgment when the two patches agree in brightness without regard to their difference in tint.[1] The author has devised a modification of the Lummer-Brodhun photometer, in which the two lights, A and B, to be compared are placed one in front and one at the side of the prism box. This form has some advantages for arc-lamp testing (see Fig. 4).

Some considerations affecting heterochromatic photometry are discussed below, but meanwhile it may be said that there are various methods for reducing the distraction caused by this colour difference in the lights compared. In the old form of Bunsen grease-spot photo-

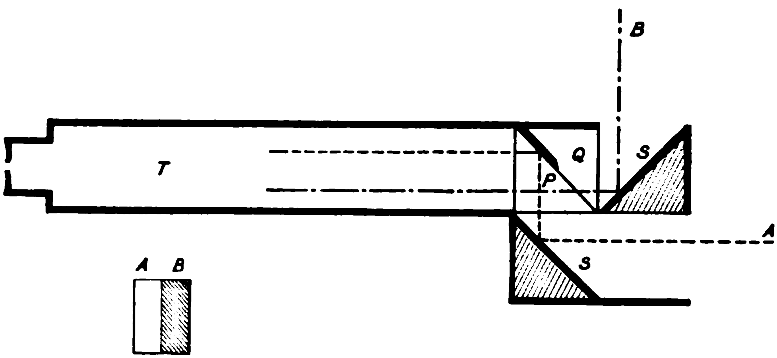


FIG. 4.—TOTAL REFLECTION PHOTOMETER (FLEMING).

P Q. Right-angle Prisms. T. Eye-tube. S S. White diffusing Screens.
A B. Field of View—the two parts illuminated respectively by light A and light B.

metry, the difficulty of making an accurate judgment as to the equality in brightness of the two surfaces to be compared, was considerable, but the difficulty was obviated to some extent in the form of disc known as the Star Disc, in which the simple grease spot of Bunsen was replaced by a sheet of tissue paper placed between two discs of thin white cardboard, in both of which a star-shaped opening had been punched out.

It is unnecessary here to attempt to make a complete classification of photometers. One which is sufficient for the present purposes is as follows:—

Photometers are divided into three principal classes:—

(A) *Intensity Photometers*, by means of which a comparison is made between the luminous intensity of two sources of light.

(B) *Illumination Photometers*, by means of which we measure the illumination in any locality in *candle-feet* or some similar units.

[1] See Lummer and Brodhun, *Zeitschrift für Instrumentenkunde*, vol. 9, p. 23, 1889; also *Ibid.*, p. 461, 1889; also *Phil. Mag.*, vol. 49, p. 541, 1900.

(C) *Spectrophotometers*, in which selected rays from the spectra of two lights are compared in respect of luminous intensity.

The intensity photometers may be classified according to the method adopted for producing two adjacent surfaces or comparing the brightness of the two surfaces illuminated by the lights compared. Thus, we have photometers which operate by :—

(*a*) Equalising the illumination of two portions of a semi-transparent or opaque screen formed of paper, porcelain, or ground glass, the one portion illuminated by one light and the other by a standard, the equalisation being effected by moving the sources of light to various distances. *Examples:* Bouguer, Foucault, Harcourt, and Ritchie.

(*b*) Equalising the two shadows of a rod made by two lights moving to different distances with or without optical dispersion of one light by a lens. *Examples:* Lambert, commonly called the Rumford, Abney, Ayrton, and Perry.

(*c*) Equalising the illumination all over a screen, one portion of which is semi-transparent and the rest opaque. *Examples:* Bunsen (grease spot), Leeson and Dibdin (star disc).

(*d*) Equalising the illumination of two white surfaces inclined at equal or unequal angles, and placed in line between the lights to be compared. *Examples:* Ritchie, Bunsen and Roscoe, Trotter, Thompson and Starling.

(*e*) Equalising the illumination of two portions of the field of view of a telescope by bringing light from two sources to each part separately by total reflection in prisms. *Examples:* Swan, Lummer-Brodhun, Weber, Krüss, Fleming.

(*f*) Equalising two fields of light by weakening one by means of crossed polarising prisms. *Examples:* Arago, Zollner, Wild, Salomons, Pickering, Nichols.

(*g*) Equalising the illumination on two portions of a white surface by weakening one of the illuminations by interposing a rotating disc having a sector cut out of it which can be varied in magnitude. *Examples:* Fox-Talbot, Napoli, Guthrie, Abney.

(*h*) Equalising two fields of illumination by the interposition of an absorbing wedge. *Examples:* Pritchard, Sabine, and others.[1]

Probably by far the largest portion of photometry of late years has been conducted by means of the Bunsen grease-spot disc, or its various modifications. The Gas Referees have recently adopted a modified form of Foucault photometer which is called a *Photoped.* This consists of a small sheet of some transparent paper without watermark, which is fixed at the bottom of a short tube, having a diaphragm in it with a rectangular aperture. The diaphragm can be moved nearer or farther from the paper. When two lights are placed not quite close together, and at different distances, they throw upon the paper two patches of light due to the light passing through the aperture. By moving the

[1] For a discussion of Illumination Photometers and results obtained by them, the reader may with advantage consult a paper by Mr. A. P. Trotter, "On the Measurement of Illumination," *Proc. Inst. Civil Engineers*, vol. 110, 1892. A number of interesting photometers, such as the diffusion photometers of Joly and Elster, are not included in the above classification.

diaphragm, these patches of light can be made to touch. One of the lights can then be altered or moved until the illumination on the screen is uniform, and from their relative distances the relative illuminations are determined. The author's assistant, Mr. A. Blok, has found that a very effective diaphragm for this purpose can be made by using an ordinary gelatine photographic plate just as taken from a packet of unexposed negative plates.

For electric glow-lamp photometry the writer has found no photometer which is on the whole superior to the Contrast form of the Lummer-Brodhun photometer, which, when skilfully used, enables a difference of less than half per cent. in the luminous intensity of the two lights to be determined.[1]

In describing the arrangements which the writer's experience has shown to be the most advantageous for glow-lamp photometry, it will be well to say a few words first on the arrangement of the photometer and the photometer room. The general impression in the minds of many electricians is that any room or corner is good enough for a photometer. In numerous electrical laboratories or testing-rooms, a wooden shelf is put up with black velvet curtains in front, and a box at each end to hold the standard lamp and the lamp to be tested, whilst the Bunsen disc or other photometer slides on a graduated bar between the lamps. A photometer of this kind embodies almost every defect a photometer can have. It reproduces, often in an aggravated manner, the defects present in a form of photometer called the Evans closed photometer, long known to be unreliable. The chief source of error in it is that reflection of stray light from the neighbouring velvet or black wood surfaces causes the illumination on the photometer disc to vary *not* according to the law of the inverse square of the distance from the source of light. A photometer consisting of a long box or narrow shelf invariably allows a good deal of light to be reflected at an oblique incidence even from black velveteen curtains. The whole principle on which intensity photometry is based, is that no light must reach the photometer disc except that coming in straight lines from the two sources. Hence it is essential not to take this for granted in any particular instance, but to verify it. In the next place, such a closed photometer, if used with a flame standard of any kind, invariably gives erroneous measurements because of imperfect ventilation. If a flame standard is to be used at all, the greatest attention must be paid to the temperature and ventilation of the photometer room. For this purpose, it should be at least 8 feet wide, 8 or 9 feet high, and 20 feet in length. Fresh air should be drawn in from the outside by means of a fan, and circulated through the room, but with the avoidance of draughts. If this is not done, and two or three people are in the photometric room employing a flame standard, it will most certainly fall off in luminous

[1] The Lummer-Brodhun photometer is in reality a very superior form of Bunsen grease-spot photometer. The principle of employing total reflection at a prism surface to construct a photometer, was made use of by W. Swan, Professor of Natural Philosophy, University of St. Andrews, See a paper by Professor C. G. Knott, "On Swan's Prism Photometer," *Phil. Mag.*, vol. 49, Jan., 1900, and reply by Messrs. Lummer and Brodhun, *Phil. Mag.*, vol. 49, June, 1900.

intensity by a sensible percentage in a short time, owing to the accumulation of moisture and carbonic dioxide in the room. Also the temperature of the room should be kept uniform, especially if electrical measurements are to be made in it. The arrangements of a suitable photometric room for glow-lamp testing are as follows:—The room, being at least of the dimensions above stated, should be painted dead black in its interior, well ventilated as described, and kept at a constant temperature. Down the centre should run a wooden railway, consisting of a pair of beams on which can travel easily wooden slabs or tables holding the lamp to be tested, the standard and the photometer, the height being such as to bring the photometer telescope or tube to a level convenient for the eyes of ordinary persons when standing.

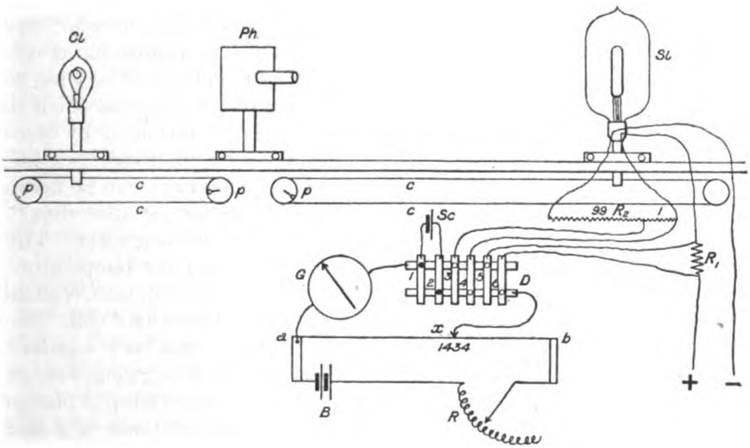


FIG. 5.—ARRANGEMENTS OF STANDARD PHOTOMETER BENCH AND POTENTIOMETER.

Cl. Comparison Lamp.
Ph. Lummer-Brodhun Photometer.
a b. Potentiometer Wire.
G. Galvanometer.
Sc. Standard Cell.
R_2. Voltage divided Resistance.
Sl. Standard Lamp.
p p. Pulleys. c c. Endless Cords.
B. Battery.
R. Rheostat.
R_1. Series Resistance.
D. Plug Switch.

The arrangements adopted after long experience in the Pender Electrical Laboratory at University College, London, and reproduced in the photometer rooms of the Edison and Swan Electric Lighting Company's Factory at Ponder's End, at the suggestion of the writer, are as follows:—The photometer employed is the Lummer-Brodhun photometer with contrast prism, and is kept fixed in one position on the railway (see Fig. 5). On the left-hand side, carried on a sliding table, is an incandescent lamp, which is called the *Comparison Lamp*, and by means of appropriate resistances this lamp can be adjusted accurately for voltage and therefore candle-power. The sliding table on the right-hand side is connected to an endless cord moved by a winch, so that the observer at the photometer can move the lamp

on this table to or from him. This slab carries a support for the incandescent lamp to be tested, so arranged that the lamp can be placed with its axis in any required direction, and also revolved on its axis by means of a small electric motor. Under the railway are placed the resistances and controlling handles for regulating the current and voltage of the lamp to be tested, and for this purpose, from the socket holding the above lamp, there come two pairs of leads, one the current leads, and the other the potential leads.

For measuring the electrical quantities, no instrument is so satisfactory as the direct-reading potentiometer. Out of a large experience, the writer can say that no ammeter or voltmeter yet made is sufficiently accurate for electric-lamp photometry. It was with this object that the writer introduced as far back as 1888 the direct-reading potentiometer, set by a Clark cell, which has been since brought into its present perfect form by Lieutenant-Colonel Crompton, and those of his firm who have assisted him. The modification which the author then introduced was that of adjusting the current through the potentiometer coils or wire, so that the fall of potential down a unit of length of the wire was equal to one-thousandth or one ten-thousandth of a volt as determined by comparison with a standard cell. Employing a Crompton potentiometer, readings of the current and voltage of incandescent lamps can be taken quite as quickly in the photometer room as by the use of any ordinary ammeter or voltmeter, and with an accuracy which is far greater. The only point to which attention need be drawn is that the temperature variation of the Clark cell being considerable, it is better to use a Weston cadmium cell, or Helmholtz calomel cell in place of the Clark cell. The operation of making measurements by means of the large bulb standard glow-lamps is as follows:—A standard lamp is selected giving, say, 16 candles at 96 volts in a certain direction. This standard lamp is placed in the testing socket with its axis upright, and set at a distance of 4 feet from the photometer disc. The distance of the comparison lamp is then varied until the photometric balance is obtained. The standard lamp is then removed from the testing socket and the lamp to be tested placed therein, and its distance varied until a photometric balance is again obtained. From the relative distances of the tested lamp and the standard, the luminous intensity of the former is determined in terms of the latter. The railway bar can, of course, be calibrated to show at once candle-power. It will be seen that this process is a form of *double weighing*. It eliminates the effect of any want of symmetry in the photometer itself. The exact candle-power of the comparison lamp does not matter, as long as it remains constant during the experiment.

In making a series of tests of incandescent lamps, it is desirable to check the setting of the comparison lamp by means of a large bulb standard, at intervals, just as the setting of the potentiometer is checked at intervals by means of the standard cell. In making photometric examinations of incandescent lamps, it is of course necessary to take the candle-power in different directions. In order to eliminate the variation in candle-power which exists in different horizontal directions when the axis of the tested lamp is vertical, a committee of the American Institute of Electrical Engineers recommended that the lamp under

test should be revolved on its vertical axis. This is not difficult with stiff filaments, but with the long high-voltage filaments now used there is a risk of breaking the filament, or forcing it against the bulb of the lamp, if the speed of revolution exceeds about two per second, and this is hardly sufficient to eliminate all flickering. In any case, the maximum horizontal and minimum horizontal candle-power should be taken, and also the candle-power in the direction of the axis of the lamp. For certain purposes, it may be necessary to take the mean spherical candle-power. The usual process is to be content with taking the maximum candle-power in a horizontal direction, but since by far the larger number of lamps are hung head downwards, in use this value alone does not give sufficient information as to the performance of the lamp, and the candle-power in the above-stated three directions should always be furnished. In the actual photometric measurements it is desirable to oscillate or move one of the lamps on a plan recommended by Sir W. de W. Abney. If the lamp under test is moved to and from the photometer in gradually diminishing arcs, it is easier to determine the exact position of balance than if this is not done. One advantage of the above described method is that the comparison lamp can be adjusted to work as nearly as possible at the same watts per candle as the lamps under test. This is especially desirable when using the Lummer-Brodhun photometer, as it is very sensitive to small differences in the spectral quality of lights compared.

Before proceeding to discuss the special difficulties connected with the photometry of arc-lamps, it may be well to describe the arrangement which the writer has found in practice to work well for determining the form of the polar curve of luminous intensity of arc-lamps.

Owing to the unsymmetrical distribution of light from an arc-lamp, it is more important than in the case of the incandescent lamp to determine the luminous intensity in different directions, and to set these out in the form of a polar curve, the radii of which represent to scale luminous intensity. Various devices have been used for this purpose, but a convenient arrangement is as follows:—On a suitable base is erected a wooden gallows about 9 feet high and 3 feet wide. From the top of this, the arc-lamp to be investigated is suspended. In the two uprights of the gallows are two openings through which pass brass tubes or hollow bearings to which are connected another rectangular frame, as shown in the diagram (see Fig. 6). The lamp is placed so that the arc A is exactly in line with the axis of these hollow trunnions. On the outside of one of the uprights is a circular scale of degrees, and the swinging frame carries a pointer, by means of which its angular position relatively to the horizon is determined. The swinging frame also carries three plane mirrors, I_1, I_2, I_3, which are set at angles of 45 degrees, and catch the ray from the arc-lamp, and reflect it down one of the hollow trunnions. The ray therefore emerges in the same direction, no matter what may be the angular position of the swinging frame. This frame can be so set as to catch a ray coming from the arc at any angle above or below the horizon. It is quite possible, by means of a standard incandescent lamp, to determine the total and constant percentage loss of light, by

the three mirrors at each of which the ray is reflected at an incidence of 45°, and hence to apply the necessary correction to the measured intensity of the selected ray. By employing a photometer and a standard glow-lamp, measurements can be made of the luminous intensity of the arc in any direction relatively to the horizontal plane

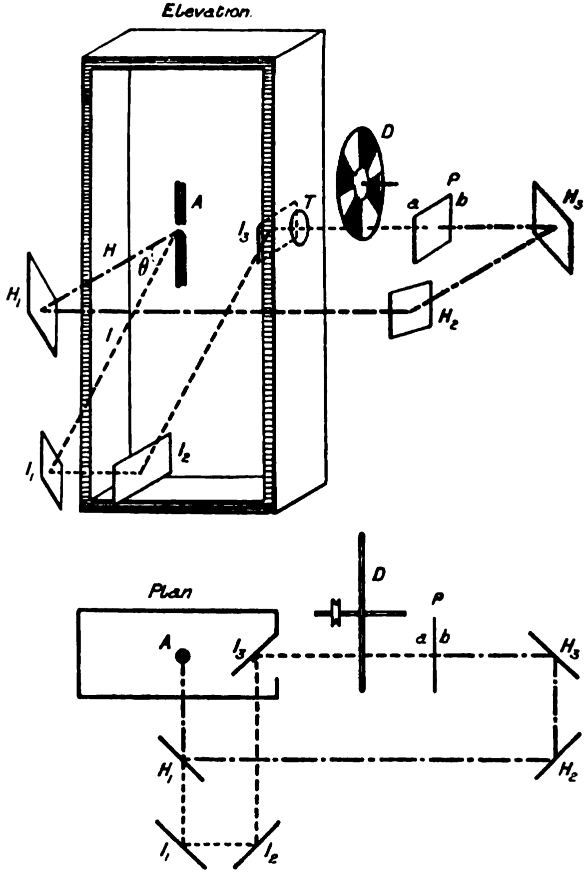


FIG. 6.—ARC-LAMP PHOTOMETER (FLEMING).

A. Arc Lamp. H_1 H_2 H_3 I_1 I_2 I_3. Mirrors.
P. Photometer Disc. D. Fox-Talbot Sector Disc.

through the arc. This direct measurement is often rendered difficult because the electric arc shifts its position continually, and there is therefore a periodic waxing and waning of the light in any direction. This difficulty, however, can be overcome by photometering the arc against itself, or, in other words, comparing the luminous intensity of the ray coming from the arc in any direction with that of the ray coming

off in a horizontal direction. This is accomplished by fixing three other mirrors, H_1, H_2, H_3, to reflect round the ray coming in a horizontal direction from the arc, and make it coincide in direction with the three times reflected ray coming from off the arc at any angle above or below the horizon. In each case the ray suffers reflection at three mirrors placed at angles of 45 degrees, hence there is no difference in the loss by reflection, and both the rays are weakened in the same ratio.[1] We have then to determine the ratio of the intensities of these two rays. One way by which it can be achieved is by employing the device, much used by Sir W. de W. Abney, viz., a rotating metal

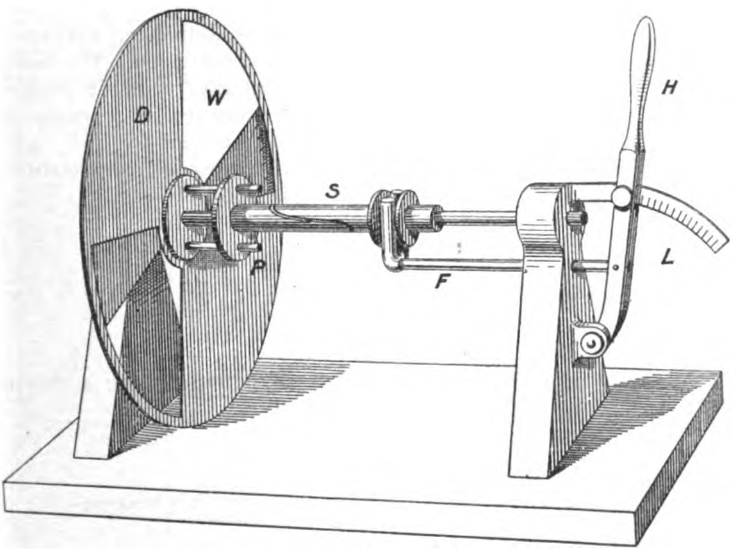


FIG. 7.—FOX-TALBOT-ABNEY VARIABLE APERTURE DISC.

disc having sectors cut out of it, the apertures in which can be more or less closed up whilst the disc is running[2] (see Fig. 7). If we interpose such a rotating disc with variable apertures in it, in the path of the brighter ray or in the paths of both rays we can weaken the stronger ray until the two are of the same intensity. By the use of a Foucault or Rumford photometer, and a pair of such rotating discs, we can accordingly determine the ratio of the luminous intensity of

[1] Many forms of arc-lamp photometer have been devised, such as that of M. Rousseau in which the ray is reflected from a mirror at various angles of incidence, but this requires a correction at every angle for loss by reflection.

[2] This method for weakening a ray of light in a known ratio was originated by Mr. Fox-Talbot, whose name is well known in connection with the development of photography. The use of a rotating disk with apertures which could be more or less closed, and through which the ray was sent, was described by him in the *Philosophical Magazine* for 1834, vol. 5, p. 331. See also Lord Rayleigh's article, "Wave Theory," *Encyclopædia Britannica*, 9th Ed.

the ray coming from the arc in any inclined direction to that emitted in a horizontal direction. The question whether the Fox-Talbot sector disc reduces the intensity of a transmitted ray in the proportion of the total open sectorial angle to 360° has often been raised. Experiments made in the Pender Laboratory for the author by Mr. W. C. Clinton support the affirmative conclusion generally accepted. An incandescence lamp was placed on a photometer bench and balanced against a Comparison lamp by means of a Lummer-Brodhun photometer. Between the photometer and the Comparison lamp a Fox-Talbot disc was interposed, and the balance between the two lamps was obtained for various illuminations by reducing the apertures of the rotating disc, and by moving one lamp at the same time to various distances. Thus the lamp being first placed at 80 inches from the photometer, a balance was found when the disc apertures were 97 per cent. open. The lamp was then moved respectively to 120″, 160″ and 204″, and the photometer balance obtained by closing the disc apertures successively to 44, 24, and 15 per cent. of full aperture reckoned as 100.

The illuminations produced on the photometer disc at these distances are therefore, by the law of inverse squares, respectively—

$$1 : \frac{64}{144} : \frac{64}{256} : \frac{64}{416};$$

or as percentages—

$$100 : 44{\cdot}4 : 25 : 15{\cdot}4;$$

and the above figures are almost precisely in the ratio of the aperture of the disc in the several experiments, viz. :—

$$97 : 44 : 24 : 15;$$

since on reducing the above figures to percentages they become—

$$100 : 45{\cdot}3 : 24{\cdot}75 : 15{\cdot}5;$$

and with the exception of the second, agree closely with the ratio deduced from the law of inverse squares.

A single observation, or rather the mean of a number of observations, taken against a standard glow-lamp will enable us to determine the mean absolute horizontal luminous intensity, and hence the polar curve of luminous intensity can be plotted out.

In taking the absolute luminous intensity of the arc, the most convenient standard to use is the glow-lamp of the large bulb pattern, which is worked at an efficiency of 2½ watts per candle. There is no reason why manufacturers of arc-lamps should not furnish on demand the polar curve of luminous intensity, because such a curve at once enables us to determine the mean spherical candle-power, and also the illumination on the surface of a roadway, due to the arrangement of any number of such arc-lamps at known heights and distances. The geometrical constructions for doing this are tolerably well known, but it may perhaps be convenient to give them here.

Let A (see Fig. 8) be an arc placed on a post X A standing on a

roadway X Y. It is required to determine the illumination at any point P. Draw the line A P, and round A set off the polar curve of candle-power of the arc as determined experimentally. Let G E F be a semicircle just touching this polar curve. On the other side of the line X A and on the base F G describe a rectangle K F G H of which the side K F is equal to the maximum radius vector of the polar curve. Draw the horizontal line through A, draw a line B D vertically through B, and through Q where A P intersects the semicircle draw Q C horizontally and produce it to L, setting off a length C L equal to A B. At P set up P M perpendicular to X Y, and make P M equal to the quotient of B D divided by $(A\,P)^2$. This can be done at once by means of a slide rule.

Then if A B represent to any scale the luminous intensity of the arc in the direction A P, M P will represent the horizontal illumination on the roadway at P.

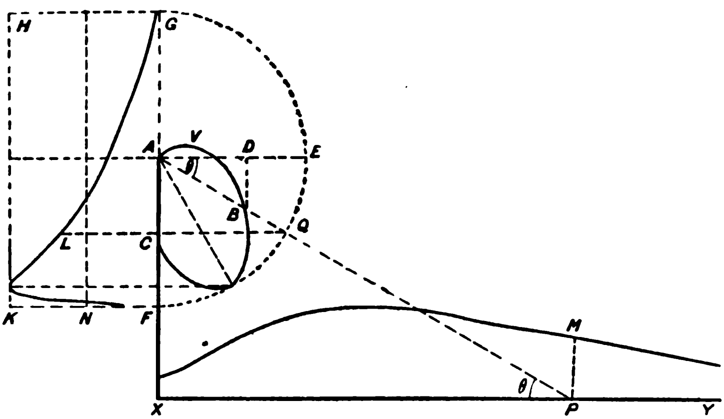


FIG. 8.—ARC-LAMP POLAR CURVE OF INTENSITY AND HORIZONTAL ILLUMINATION CURVE.

If other radii of the polar curve are drawn and the same construction followed out, then the extremities of all the lines similar to C L will define a curve G L F, called the Rousseau curve, which has the property that its mean ordinate F N is the so-called "mean spherical candle-power of the arc."[1] Similarly, the upper extremities of all lines like P M define a curve X M Y, the ordinates of which define the illumination on a horizontal surface.

The proof is easily given of these propositions. Let the angle D A B be denoted by θ. Let I be the luminous intensity of the arc in the direction of A B. Hence $AB = CL = I$. Let the radius of the semicircle A F be denoted by R. Then if we consider θ to increase by an increment $d\theta$, the corresponding increment of the arc of the semicircle is $R\,d\theta$. If the whole figure revolves round A X as an axis,

[1] See *La Lumière Électrique*, vol. 37, p. 415.

then the area of the zone swept out by this elementary arc is $2\pi R^2 \cos\theta\, d\theta$, and the whole quantity of light falling on the zone is $2\pi R^2 I \cos\theta\, d\theta$.

If we call I_0 the "mean spherical luminous intensity," then I_0 is defined by the equation—

$$4\pi R^2 I_0 = 2\pi R^2 \int_0^{\pi} I \cos\theta\, d\theta,$$

or—

$$2 R I_0 = \int_0^{\pi} R\, d\theta \,.\, \cos\theta \,.\, I.$$

The right-hand side of the above equation denotes the area of the Rousseau curve G L F, and the left-hand denotes the area of the rectangle N F, F G, where N F is the mean ordinate of the curve G L F. Hence N F represents the mean spherical luminous intensity I_0. Again, the illumination at P on the horizontal plane is equal to $A B \sin\theta / A P^2 = B D/(A P)^2$.

Accordingly, if we have the polar curve of luminous intensity of an arc when included in its globe, we can, by means of a simple geometrical construction on the drawing-board, set out a curve whose ordinates represent the illumination produced on a roadway by any number of such arc-lamps placed at any distances and at any heights. For the illumination produced by all the lights is the sum of the separate illuminations. As a general rule, it will not be necessary to consider more than the two adjacent arc-lamps in obtaining the resultant illumination. We are able, therefore, to set out a curve along a line joining the base of the two arc lamp-posts showing the maximum, minimum, and mean illumination in candle-feet, or any other similar units, on the roadway, and decide exactly as to the proper heights and distances of the arcs to obtain a given result.

If the polar curves of luminous intensity of arc-lamps of various descriptions are available, they enable us to make a comparison between them as street illuminants when arranged in any suggested way, without further experiments. Manufacturers of arc-lamps are not, however, in the habit of furnishing this very necessary information, but there is no more reason why they should not do so than that makers of engines should not furnish an indicator diagram for an engine.

With this polar diagram at hand we have the means of predetermining the effect of any proposed arrangement of open or closed, direct-current, or alternating-current arcs, arranged at stated distances or on posts of stated heights. When once the lamps are in position, an illumination survey can be made by means of an illumination photometer, and extensive researches of this character have been carried out in past years by Sir W. H. Preece and Mr. A. P. Trotter.[1] What is required, however, is a means of predetermining the illumination before making expensive experiments. It is usual in these surveys to

[1] "The Distribution and Measurement of Illumination," by Mr. A. P. Trotter, A.M.Inst.C.E. (*Proc. Inst. Civil Eng.*, vol. 110, 1891–1892).

calculate or to measure the illumination either on the pavement surface or at a height of about four or five feet above the pavement. The measurement most required is that of the illumination on a horizontal or vertical surface about five feet above the pavement or road surface, because it is on the illumination at this point that our ability to distinguish objects in the street depends.

Various photometers have been designed for determining by one observation what is commonly called the "mean spherical candle-power" of the arc. M. A. Blondel has devised several appliances for making a measurement of this description. One instrument, called by him the *Lumenmeter*,[1] collects the total flux of the light from the arc, and concentrates it upon a semi-transparent screen, which then forms a secondary focus, the luminous intensity of which is determined. Whilst this appliance is valuable in comparing together the luminous efficiency of different arcs, it does not obviate the necessity for determining the polar curve of luminous intensity, since this last curve, as shown above, affords the means of predetermining the exact distribution of illumination.

III. Heterochromatic Photometry.

We may in the next place consider some interesting questions connected with the photometry of lights of different temperature, and therefore, in general, of different spectral character. Any pair of lights may be defined as *Isochromatic* or *Heterochromatic*, as follows :—

If we form the spectra of two lights and alter the brightness of one of them until the spectra match each other in brightness at one common wave-length, say in the yellow, then if the spectra are matched at all other corresponding points in brightness at the same time, the lights are said to be isochromatic. On the other hand, if the spectra of two lights, when equalised at one common wave-length in brightness, are unequal in brightness at all other points, they are said to be heterochromatic. Thus, for instance, if we form the spectra of a candle and an arc-lamp and reduce them to the same brightness of the yellow, the candle spectrum would be the brighter of the two in the red, but the arc-lamp spectrum would be much the brighter of the two in the violet. Hence, this fact introduces us to the questions : In what sense can we speak of the *candle-power* of an arc-lamp ? Can any scientific meaning at all be attached to this common expression ? The human eye has two distinct powers corresponding to the two principal qualities of a ray of light, namely, a power of colour discrimination, and a power of brightness discrimination. We can pronounce a judgment upon two adjacent illuminated surfaces and say that they are either alike or unlike in colour ; but apart from the colour difference we can also pronounce a judgment in respect of their illumination or brightness. This last judgment is more difficult in proportion as the two patches of light approximate to pure spectral colours. In judging two white surfaces illuminated by pure red and blue light respectively, there is room for a large difference of personal opinion as to their

[1] See *L'Éclairage Électrique*, March, April, May, 1895.

relative brightness, whereas if the two incident lights are very impure, that is to say, much mixed with white light, then it is possible for several persons to make a closely identical judgment as to the equality or inequality in respect of brightness of the illuminated surfaces.

Doubts have sometimes been raised whether we *can* compare differently coloured surfaces or lights in regard to brightness or illumination alone. It is clear, however, that any compound ray, whether reflected from a surface or radiated by an illuminant, can be expanded into a spectrum; and each individual ray compared as regards brightness with the corresponding ray in some standard of light. Hence the effect of the compound ray is to produce a certain resultant or integral brightness which is a consequence of all the separate intensities or brightnesses of the rays of which it is composed, as well as a certain compound colour sensation which is due to the sum of all the separate colour effects of the various wave-lengths.

The opinion has been advanced by Lépinay and Nicati, and has also been supported by Blondel and others, that the eye possesses a *form-* or *detail-* discriminating power, which is not identical with its power of discriminating a difference in brightness. It may be argued, however, that this detail-discriminating power depends essentially upon the brightness-discriminating power of the eye. If, for instance, we are reading a book, or examining a pattern of black lines drawn on a white ground, we have really before our eyes portions of a surface which have unequal reflecting powers, and hence, when illuminated, there is a difference in the brightness of the two parts. We guide the eye along the boundary of a letter by the aid of the difference in brightness between the adjacent parts, and we cannot distinguish any pattern on a surface in which, between the adjacent portions, there is no difference either in brightness or colour. On the other hand, Lépinay and Nicati have asserted that if we equalise, what we may call, the integral brightness on two separate white surfaces, one illuminated by light of one kind, say blue, and the other illuminated by light of another kind, say red, then we can more easily distinguish a black pattern drawn upon the surface illuminated by red light, than upon the surface illuminated by the blue. The above investigators have stated that if yellow and blue light produced by any prismatic means are adjusted to produce equal apparent brightness when falling upon two parts of a uniform white surface, then when these rays are allowed to fall upon a printed book the type is more easily read which is illuminated by the yellow light than that illuminated by the blue.[1] It may therefore be the case that the integral brightness of lights of different spectral compositions is not a measure of their power of bringing out a detail printed in black on a white ground. If so, we must include amongst the powers of the eye a definite detail-discriminating power, and among the qualities of a ray of light a detail-revealing power, understanding by this term "detail" a fine pattern of black on white, such as a printed page or handwriting, or fine

[1] Macé de Lépinay and W. Nicati, *Journal de Physique*, vol. 2, p. 75, 1883.

black lines or black dots on a white ground. It may be noted in passing that we cannot detect the existence of a black line on a white ground unless the width of the line subtends a certain angle at the eye. A line having an angular width of 1′ can certainly be seen. This corresponds with a line 1 mm. in width viewed at a distance of 344 centimetres, or about 11 feet, but a black line on a white ground having a width subtending an angle 1″ certainly cannot be seen.

This ability to see a black line on a white ground is dependent on the illumination of the surface. Thus, if we draw a series of parallel black lines of gradually increasing width, we shall find that they cease to be visible one by one, either as we move farther away from them, or as the illumination on the paper is decreased. The same thing is true of white spots of various angular magnitudes placed on a black background. Hence, the power to discriminate a number of black lines having a given angular width ruled on a white surface, may become a measure of the illumination of the surface. If on a white ground we place a number of black lines or black dots, or on a black ground a number of white dots of such a diameter that at the distance of distinct vision they subtend an angle 1′; and if we illuminate one portion of this ruled or dotted surface, one by a standard illumination and the other by a light under test, we may assert the two portions to be equally illuminated when we can with equal ease or sharpness distinguish the pattern on the two portions.

This statement, however, is largely qualified by the reflex power of the pupil of the eye to vary in aperture according to the illumination of the object regarded. If we could control the aperture of the pupil, there might possibly be a definite discriminating power corresponding to each grade of illumination. As it is, the lower the illumination the more we "strain" the eye in the effort to see detail.

It appears that this method of judging the equality of illumination of two parts of a white surface does not lead to quite the same results as the process of judging the integral brightness of the surfaces. Lépinay and Nicati have accordingly distinguished these two methods by calling them the "method of equal brightness" and the "method of equal distinctness or sharpness," and M. A. Blondel, in discussing this subject, has pointed out that we may distinguish the value of a standard according to its "luminous intensity" or its "visual intensity," or we may perhaps translate these expressions somewhat freely by calling them "*the power of creating brightness*" and "*the power of revealing detail.*" [1]

The purposes for which we require artificial light are partly for revealing what we call the colour differences between objects, and partly for revealing detail. In the one case the chromatic quality of the light is of great importance. In the second place, the chromatic quality is not of so much importance, provided it is accompanied by

[1] The reader may be referred to a paper by M. A. Blondel read before the Congress of Electricians at Chicago, 1893. See also *The Electrician*, vol. 32, p. 117, for curves representing the distribution of *visual intensity* and *luminous intensity* in the spectrum ; also for an excellent discussion of the problem of heterochromatic photometry.

sufficient intensity or brightness. Thus, for the purpose of reading, we are far less concerned with the chromatic quality of an illumination than we are when we are providing an illuminant for a picture gallery or a dye-house.

Another matter in connection with heterochromatic photometry of special interest is that known as Purkinje's phenomenon, which is intimately related to the general law connecting stimulus and sensation. The above phenomenon is best illustrated by the following experiment :—

We take a white right-angled wedge and illuminate one side by a red light, and the other side by a blue light, and adjust the distances of these two illuminants until we obtain what we consider is an equal illumination on the two adjacent sides of the wedge. If we then move in both these lights to half their distance from the wedge—in other words, make the *objective brightness* of the surfaces fourfold, we find that the retinal stimulation or the *apparent brightness* of the two surfaces are no longer the same. It is therefore clear that although the retinal sensation of brightness increases with the objective or actual illumination of the surface, it does not increase according to the same law for all colours.

Fechner's law connecting sensations and stimulus is sometimes stated in the form that *sensation varies as the logarithm of the ratio of stimulus to minimum stimulus*, understanding by the latter term the stimulus which has to be applied before any sensation at all results.[1] Hence, it is clear that if we could set out in the form of a curve for the different colours, the objective intensity and the retinal sensation for different colours, these would be represented by different curves. The curve corresponding to a red light would be steeper than the curve corresponding to a blue light (see Fig. 9). It follows from this that if we illuminate such a simple wedge photometer on one side by a candle, and on the other side by an arc-lamp, the ratio of the distances at which these two illuminants must be placed in order to produce what we consider to be an equal brightness on the two surfaces, will depend upon the degree of that surface brightness. Hence, there is no fixed ratio between the luminous intensity or illuminative power of an arc-lamp and a candle in regard to the brightness they produce on a white surface, apart altogether from their colour difference.

In view of these facts, great authorities, such as Von Helmholtz, have declared that there was no such thing as heterochromatic photometry; in other words, no possibility of defining in any scientific sense the candle-power of an arc. With regard to colour-distinguishing power, or colour-revealing power, it is perfectly clear that no scientific meaning can be attached to the term "candle-power of an arc." Our standard light, as regards revealing the so-called natural colours of

[1] If S stands for sensation and I for stimulus, and i for the least stimulus which will create recognisable sensation, then according to Weber's investigations on Fechner's Law $S = k \log \frac{I}{i}$, where k is some *constant of sensation*. See also Principal C. Lloyd Morgan, F.R.S., on "Studies in Visual Sensation," *Proc. Royal Soc.*, vol. 68, p. 459. The Croonian Lecture, March 21, 1901.

objects, is *daylight*, say the light from a northern sky, such as that which an artist admits to his studio. The same surfaces viewed by the aid of other illuminants may create totally different sensations in the eye, and it is a question whether any single numerical coefficient can be attached to these illuminants defining their colour-revealing powers in terms of daylight, taken as a standard. On the other hand, if we separate out the sensation of brightness from that of colour, we can then define the power of an arc in terms of that of a candle, as regards its power of producing brightness on a white surface, *provided we define what that brightness shall be.* If we take as our standard of brightness one *candle-foot*, that is, the illumination produced by one candle placed at a distance of one foot from a white surface, then we can by one single number express the ratio of the two lights in producing brightness of this kind, but the same ratio is not applicable to other degrees of brightness, and hence, generally speaking, there is no such thing as an absolute "candle-power of an arc." In consequence of Purkinje's

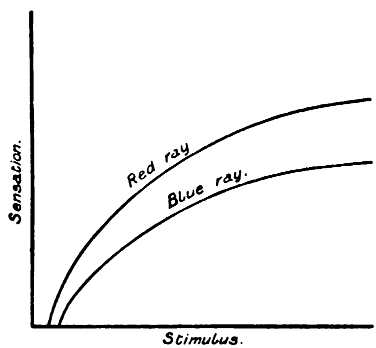


FIG. 9.—CURVES ILLUSTRATING THE PURKINJE PHENOMENON.

phenomenon, an arc-lamp has less candle-power the nearer the eye is to it.

It has therefore been proposed that we shall define the ratio of two heterochromatic lights by means of their detail-distinguishing powers. This could be done if we agree on a certain pattern which shall afford, as it were, a standard of discrimination. Suppose, for instance, that we rule on a white surface a number of black lines 1 mm. wide and 1 mm. apart; then the width of these lines subtends an angle of 1′ at a distance of 3·44 meters. We can by photography reduce this diagram to such dimensions that the lines subtend the same angle at a distance of 10 inches, which is about the distance of distinct vision. If we cover the two sides of the Ritchie wedge or a Bunsen disc with two pieces of paper equally ruled with the above pattern of lines, or on which the above standard has been photographed, then we might define the equality of brightness or illumination on the two surfaces of the disc or wedge as being those which enable us to distinguish with equal ease the ruled pattern on the two surfaces. The same test can

be applied using white dots of given angular magnitude on a black ground as the test object. Such an equalisation may be called an equalisation of distinctness, as compared with an equalisation of mere surface brightness on two white surfaces. The first may be called the *method of equal distinctness,* and the second may be called the *method of equal brightness.* The two methods do not lead to precisely the same results when we employ two such illuminants as a candle and an arc-lamp.

Some of the above statements have been tested by experiments recently made in the Pender Laboratory at University College, London. The Purkinje phenomenon can be easily shown in the following manner : A cube of wood is covered on two adjacent sides with fine white card. Two incandescent lamps are placed in wooden boxes, the front of one being covered with red glass and the other with bluish-green. The kind of glass that is convenient to use is that employed for railway signals, known as ruby red and signal green. These lamps are placed on either side of the cube, so that one surface of the cube is illuminated by red light and the other by green, the sides forming equal angles with the rays of light. The lamps are placed about 6 feet apart. The cube must then be so placed that on looking at the edge from a distance of 4 or 5 feet the two surfaces appear equally bright, one being red and the other green. The two lamps are then moved in each to half their distance, and it will be found that the side illuminated with red light is now much brighter than the other.

If, on the other hand, the lamps are moved away to double their distance, the green side predominates in brightness.

Experiments have also been made to obtain a standard for testing the discriminating power of the eye in various illuminations. This has been done in the following manner : It is possible to buy a certain kind of black printed calico with white spots upon it placed at equal intervals, these white spots being 2 mm. in diameter. If a square of this material is photographed, it is possible to obtain a photograph consisting of black spots on a white ground of such a size that when the photograph is viewed at a distance of 10″, which is the distance of distinct vision, the diameter of the spots subtends an angle of 1′. By preparing two paper photographs of this description, consisting of black or white dots having an angular magnitude of 1′, and placing these photographs on either side of a Ritchie wedge, it is easy to balance two lights placed on the two sides of the wedge, not with regard to their power of making equal surface brightness, but with regard to their power of equally revealing detail.

A difficulty, however, that has presented itself is that this photometric method does not appear to be sufficiently sharp. One can change the intensity of one of the lights by a percentage which would make itself at once evident in an ordinary photometer, without changing in a very marked degree the discrimination of the detail. This, however, is undoubtedly connected with the reflex power of the eye to accommodate itself to different illuminations on the surface regarded. If the illumination falls off on one side, the pupil of the eye, in looking at that surface, immediately expands in the effort to search for more

detail. This matter does not seem to have received sufficient attention in many researches in which the power of the eye to see fine lines has been used as a measure of brightness.

The author has, however, found that the difficulty arising from the reflex adjustments of the pupil of the eye can be greatly, if not entirely, overcome by the following simple device :—A thin metal plate is placed in front of one eye, which is pierced with an aperture 1 mm. in diameter, and through this small opening the diagram on the photometer disc or wedge is examined. The light that reaches the eye is therefore limited by the angular aperture of this small opening, and no alteration in the pupil of the eye, within the limits naturally occurring, can influence the amount of light entering the eye. Nothing can alter it but the illumination of the disc looked at.

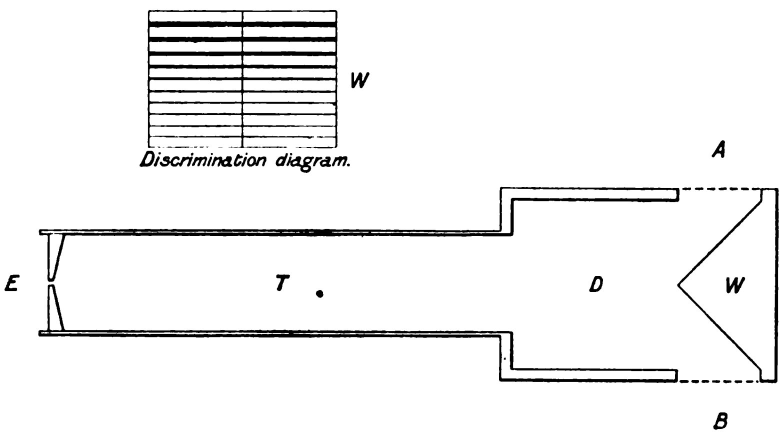


FIG. 10.—DISCRIMINATION PHOTOMETER (FLEMING).

W. Ritchie Wedge covered with Ruled Discrimination Diagram W.
E. Pinhole Eyepiece. A and B. Two Sources of Light. T. Eye piece Tube.

During this examination of the disc through the small aperture the other eye must, of course, be closed. Any one can try the experiment by pricking a hole in a visiting-card with a large pin, and holding this aperture exactly in front of one eye.

If, aided by this simple device, we examine a sheet of black paper, or black calico, on which there are small white spots or narrow white lines, it will be found that as the illumination is gradually decreased upon the screen, the spots vanish with extreme sharpness at one point. It follows, therefore, that by the use of such an "artificial pupil" of constant size, the process of photometry by the discrimination of a standard black and white pattern is rendered much more exact.

The arrangements most convenient to use for such a *discrimination photometer* are a brass tube, having at the end close to the eye a brass plate pierced with an aperture 1 mm. in diameter (see Fig. 10). By the aid of this tube we examine a Ritchie wedge, the two sides of which are covered

over with white paper ruled with black lines of various widths and placed on the sides of the wedge, or else with dead black paper, on which there are small white spots or parallel white threads one-fifteenth of a millimetre in diameter. These spots or lines, when regarded from the distance of most distinct vision—namely 10 inches—have an angular magnitude of 1 minute. Such a standard paper can be prepared by photography without difficulty, and it may be possible to agree upon a *standard discrimination pattern*, consisting of such white dots one-fifteenth mm. in diameter, placed, say, 1 mm. apart, and examined at a distance of 250 mm. through an aperture 1 mm. in diameter placed close to the eye. Two lights are then said to produce equal illuminations on this disc, if when so regarded we see the pattern on each part with equal distinctness.

The question which remains to be decided is which of these two methods best gives us a measure of the practical value of the illuminant. Before, however, we can construct a photometric method, we must know the law according to which the effect varies. The assumption which lies at the root of all present methods of photometry is that the brightness of a surface varies inversely as the square of the distance of the illuminating source from it. The postulates made are that equality in retinal sensations implies equality in objective brightness or illumination, and that actual illumination must vary inversely as the square of the distance from the luminous source, in consequence of the rectilineal propagation of light. If the detail-distinguishing power of the eye does not vary *pari passu* with the illumination of the surface, we have no right to assume that we can read equally well by the light of four candles placed two feet away from the page as by one candle placed one foot away. If an arc-lamp at a distance of 10 feet renders a certain black and white detail as clearly as a candle placed one foot away, we can infer nothing about the "candle-power" of the arc until we know how many candles placed at 10 feet away are equivalent in detail-revealing power to one candle placed one foot away from the surface. Experiment shows that the detail-revealing power of four candles at two feet, and nine candles at three feet, and one candle at one foot are practically the same. Hence, if in the above case of the arc and candle we find that an equality of detail-revealing power results from the arc at 10 feet and the candle at one foot, we can say that the arc in question has 100 candle-power. Suppose, however, we compare the integral brightness of two adjacent white surfaces produced by these two illuminants respectively, at the distances named, we should then probably find that the arc-illuminated surface looked brighter than the candle-illuminated surface. The arc-light contains rays that practically add nothing to its detail-revealing power, but they do add to its integral brightness-producing power.

The sum and substance of the foregoing discussion is that our methods of defining luminous intensity are still imperfect. The term "candle-power of an arc" has no scientific precision as at present used, and we must seek for some better basis for the numerical evaluation of an arc-lamp.

The difficulties of heterochromatic photometry, and especially the

personal difficulty experienced by many observers in distinguishing between the general brightness of two surfaces and their colour difference, has led to many suggestions with the object of putting the photometry of lights of a different spectral character on a more certain basis. Two of these methods are sufficiently important to deserve mention here. The first is that due to Crova, which is based upon absorption. The old plan of holding a piece of red or green glass in front of the eye when comparing, by means of the photometer, an arc-lamp with a candle or glow-lamp is, of course, utterly unscientific, and the figures obtained of no value whatever. Crova's method depends on the fact discovered by him (see *Comptes Rendus*, vol. 65, p. 572) that the integral brightness of two nearly white lights are in the ratio of the brightness of the rays in them having a wave-length $\cdot 582\mu$. Hence, if by means of an absorbing medium we select from two heterochromatic lights the rays approximately of this wave-length and determine their relative intensity, we have, according to Crova, a figure which gives us the relative brightness of the two lights. For this purpose, Crova employs a solution consisting of sublimated anhydrous ferric chloride 22·321 grams, crystallised nickelous chloride 27·191 grams, dissolved in distilled water, and the volume brought up to 100 cubic centimetres at 15 degrees centigrade. This solution is placed in a glass trough, and transmits radiation of a wave-length lying between $\cdot 630\mu$ and $\cdot 534\mu$ having a well-marked maximum at $\cdot 582\mu$.[1] If this trough is held in front of the eye when making a photometric comparison between an arc lamp and a candle, and if the distances of the illuminants are adjusted so that the two parts of the photometer disc seen through this solution are of equal brightness, then, according to Crova, the luminous intensities of the two lights are inversely as the squares of their distances from the screen. It is certain, however, that Crova's method can only be applied within limits. If the spectral character of the two lights is very different, it is unquestionably inapplicable.

Another method for eliminating the colour difficulty in the photometry of dissimilar lights is by employing the method of "flicker" suggested by Professor O. N. Rood in 1893.[2] Rood constructed a photometer as follows:—A Ritchie wedge with white surface has placed in front of it a prism or a lens in such a manner that on looking through it the eye sees only one of the surfaces of the wedge at a time. If the prism or lens is made to vibrate rapidly, so that alternate glimpses are obtained of the two sides of the wedge, we have what is called a "flicker photometer." If the two sides are illuminated by heterochromatic lights, then on employing the vibrating prism the difficulty of determining when the two sides on the wedge are equally bright, apart from their colour difference, is reduced.

The principle of the flicker photometer was discovered by Professor Rood in the course of some experiments with a Maxwell colour top.

[1] μ = ·001 millimetre. *Comptes Rendus*, vol. 119, No. 16, p. 627; Oct. 15th of *Electrician*, vol. 33, p. 754; or Palaz, *Traité de Photometrie Industrielle*, p. 82.

[2] *Science*, vol. 7, 1898, p. 757. Also *Science Abstracts*, vol. 2, Abstract 26. Also see *American Journal of Science*, vol. 46, p. 173, 1893.

The principle involved is that if two surfaces are alternately presented to the eye, which are differently illuminated, then a certain peculiar flicker is produced, which is destroyed if the surfaces are made to be equally bright. The two surfaces must, however, alternately fill up the whole field of view of the eye, and be, as it were, superimposed. The flickering effect then disappears, provided that the surfaces are equally bright, no matter whether they are of the same colour or not.[1]

Another variety of flicker photometer has been described by Professor F. P. Whitman.[2] From a circle of white card, which is fixed to the axis of a motor, he cuts away a semicircular segment. This disc is placed on the photometer bench so as to make an angle of 30 degrees with the line of light. Behind this disc is placed another fixed sheet of white card, inclined at an angle of 60 degrees to the revolving disc. The two lights to be compared are placed on either side of this arrangement, and on revolving the disc and looking in the proper position we obtain intermittent glimpses of the white card behind. The brightness of the two surfaces—namely, that of a disc and the card—are then equalised by moving the lights, and this equality in brightness is known to exist when the "flicker" just vanishes. The author has made a slight modification of the above form of flicker photometer by employing a white card disc cut in the form of a Maltese cross, with the open sectors equal in magnitude to the cross arms, and using the disc on the axis of a motor as above described (see Fig 11). Another compact form of flicker photometer devised by the writer contains in a box the screen and fan driven by clockwork at just the right speed. It is quite an easy matter to compare by means of it an arc-lamp and a candle.

Mr. A. Vernon Harcourt has mentioned in a paper on "Photometry by the Pentane Standard" that his attention was drawn by Mr. Dibdin, chemist to the late Metropolitan Board of Works, to the fact that a *star disc* affords a much better means of comparing heterochromatic lights than the simple Bunsen *grease-spot disc*. In using the ordinary Bunsen grease-spot disc for the comparison of heterochromatic lights, the writer has found that the colour difficulty is partly eliminated by throwing the eye out of focus. In other words, not endeavouring to obtain too sharp a view of the object looked at.

It was shown in 1877 by Charpentier, and Donders in 1880, that the so-called *yellow spot* in the retina of the eye is less sensitive than the remainder of the retina to the most refrangible rays. Hence the judgment which is formed as to the relative brightness of two adjacent surfaces different in colour, will depend upon the angular magnitude of these surfaces. If the two surfaces do not subtend an angle at the

[1] According to the investigations of E. S. Ferry on "Persistence of Vision" (see *American Journal of Science*, vol. 44, September, 1892), the duration of a visual impression upon the eye is not much affected by colour, but almost entirely determined by brightness, and the duration (D) varies inversely as the logarithm of the brightness (B) of the light, or

$$D = \frac{1}{k \log B}.$$

[2] *Science Abstracts*, vol. 2, Abstract No. 28. Also *Physical Review*, vol. 3, p. 241, 1896. See *Proc. Brit. Association*, Aberdeen, 1885.

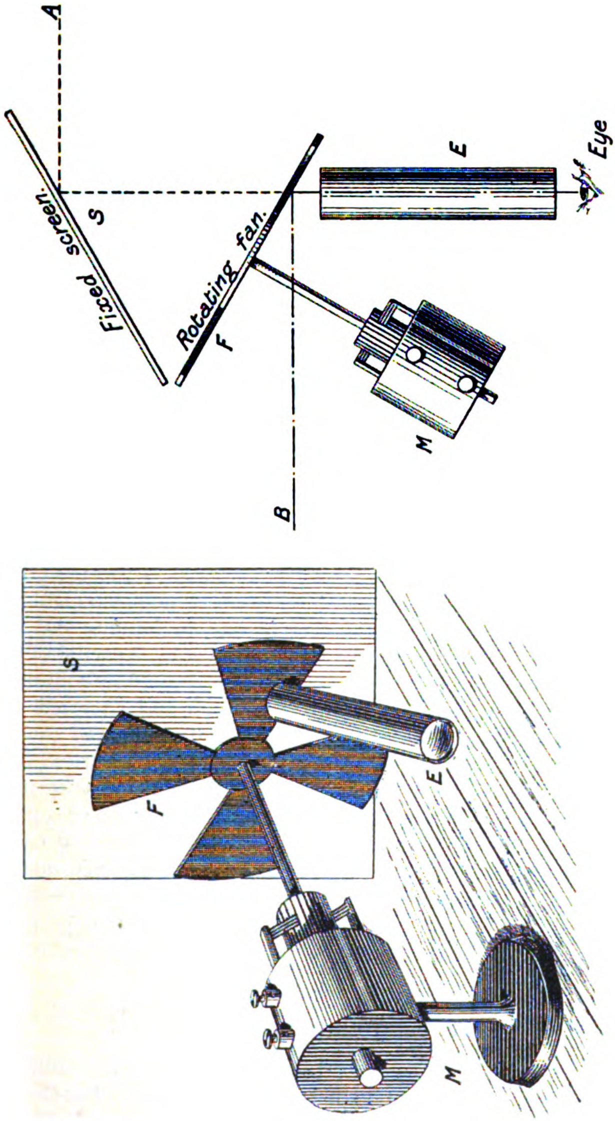


FIG. 11.—FLICKER PHOTOMETER.

M. Motor carrying White Maltese Cross Fan F. S. Fixed Screen. E. Eye-tube. A and B. Two Sources of Light.

eye greater than 45′, then there is a selective action in the eye which reduces the colour difference between the two patches, and renders it more easy to decide as to their relative brightness. If, however, the patches to be compared are much smaller than this, there is a considerable increase in difficulty in deciding as to their general brightness.

Before heterochromatic photometry is placed on a perfectly satis-

factory basis, we require to determine and to define more closely what it is we are comparing, or desire to compare. We want, if possible, some means of defining how far any given illuminant differs from daylight in colour-revealing power for certain standard coloured surfaces.

This may be difficult to do numerically, but it is probably not impossible. Considering various surface colours produced by paint or dyes, we find, for example, that certain shades of green affect the eye differently by daylight and by candlelight or arc-light. It may be possible to define in some numerical manner the degree of this difference. If, for instance, we are engaged in lighting a picture gallery so that it can be visited at night, our object is to produce an illumination which as nearly as possible will reproduce daylight in its effect on the pictures. At present there is no means of describing in any definite manner how far any given illuminant is appropriate for this purpose or not.

In the next place we require to arrange and define a standard detail pattern, in order that we may determine the quality of any given light in revealing detail; and finally, with respect to the integral brightness, we have to determine and define a standard of brightness or illumination in the production of which the lights considered should be compared.

The mere term "candle-power of an arc" is unquestionably too vague to satisfy requirements at the present day, in defining the value of a given electric arc-lamp as an illuminating agent. Apart altogether from the difference in the distribution of the light created by continuous-current arcs, and alternating-current arcs, open and enclosed arcs, flame arcs, and other varieties of arcs with specially prepared carbons, there are peculiarities about the light emitted from these various forms of arc-lamp which render them best suited for particular forms of illumination, and not sufficient information of scientific value is gained by simply describing them as arcs of so many mean spherical candle-power, or so many watts. Our ideal light is daylight. We ought to be able to define how far any artificial light can act as a substitute for daylight in enabling us to see surrounding objects in their proper colours, with their proper details and their proper brilliancy or relative brightness.

IV. Photometric Units.

We may in conclusion make a brief reference to the subject of photometric units and International agreements thereon. The Congress of Electricians at Geneva in 1896 adopted a nomenclature as follows:— They accepted as the names of the five fundamental photometrical quantities the terms, (1) *Luminous intensity*, or *Intensity*. (2) *Luminous flux*. (3) *Illumination*. (4) *Brightness*, or *Intrinsic brightness*. (5) *Lighting*, or *Quantity of Light*.

They adopted as the unit of *luminous intensity* the *candle*, and defined it as being practically represented by the *decimal candle* or *bougie-decimale*, which a previous Congress in 1889 at Paris had defined as the twentieth part of the light emitted normally by one square

centimetre of platinum at its melting point. The 1896 Congress further asserted that this decimal candle might be practically represented by the Hefner unit.[1] As the unit of *luminous flux* they adopted the word *Lumen* to signify the light sent out from a unit source through a unit solid angle. Following the decision of the Congress held in 1893 at Chicago, they defined the unit of illumination as a flux of one lumen per square meter, and it *a Lux*,[2] and the other units were specified as in the table below :—

Photometric Quantities.	Units.	Symbols.
Luminous Intensity ...	The Candle	I
Luminous Flux	The Lumen	Φ
Illumination	The Lux	E
Intrinsic Brightness ...	Candles per square centimetre	i
Quantity of Light ...	The Lumen-hour	Q

The resolutions of Congresses are often carried at the instigation of one or more influential or persuasive speakers, but it is a matter of regret that we have not in these matters what the politicians call a *Referendum* to the general body of electricians. No Congress can force a term into use which does not commend itself to the mind of the ordinary worker. In this case one cannot but wish that the resolutions adopted had been previously more discussed in the technical press.

In the first place, the *Candle* is too small a unit of luminous intensity for the purpose of electric photometry. The unit of lighting adopted now for a long time past by electrical engineers has been the 30-watt glow-lamp which when working at 3 watts per candle gives a light of 10 candles. Furthermore, electricians are accustomed to reckon out the whole of the lighting of a supply station which is conducted partly by arc-lighting and partly by glow-lamps of various sizes, in its equivalent in 30-watt glow-lamps, which used to be called 8-candle lamps, but as a matter of fact are nearer 10-c.p. Again, a 10-candle lamp is now the photometric unit adopted in gas-light photometry by the Gas Referees. The Carcel lamp, the French official standard, has a value not far from 10 candles. Hence the candle is becoming a thing of the past, both as a practical illuminant and as an actual standard in photometry. We have got rid of the article itself, why should we retain the name? It is like continuing to reckon lengths in "barleycorns," three of which were said to make an inch; and if the candle is no longer in use in practical photometry, it will soon have to be expunged from the Statute book as the legal unit of light. At the present time it may almost be called archaic, a thing to be preserved in museums, but not to have its name perpetuated as a unit of light in every way too small for modern purposes. A unit of light of

[1] See *Rapport sur les Unités Photométriques*, par M. A. Blondel. *Congrès International des Électriciens*, Genève, 1896.

[2] The word *Lux* was originally suggested by Sir W. H. Preece, at the 1889 Paris Congress of Electricians, as the name for a unit of Illumination, and applied by him to express an illumination equal to a *Carcel-Metre*, nearly equal to one *candle-foot* in magnitude.

convenient magnitude for the purposes of electric lighting is that which is given by the 30-watt glow-lamp or by the Harcourt pentane lamp as adopted by the Gas Referees.

Instead of calling this standard of luminous intensity *ten candles*, why not call it *one lamp?* The word *lamp* is a short, common word existing both in French and German, and therefore not presenting anything strange in sound.[1] A light which we now call 10-*candle power* would be called *one-lamp power*, and similarly lamps of 20-, 50-, and 100-candle-power would then be called lights of *two-lamp power*, *five-lamp power*, and *ten-lamp power*. These simple multiples are more convenient than the present 8-, 16-, and 32-candle multiples which are in use for glow-lamp classification. These last multiples were only adopted originally because at the outset electric-lighting people copied gas-lighting people in everything. We put our wires originally into gas brackets, fixed our electric lamps to gas chandeliers, and selected as the standard glow-lamp one which gave the same light as an argand gas-burner consuming 5 cubic feet per hour. It would appear, therefore, that a case can certainly be made out for reckoning luminous intensity in larger units than a candle, each of which is called *one-lamp power*, and equivalent to what we now call 10-candle power.[2] This would have another advantage, because the unit of brightness or illumination would then be the *Lamp-metre*, namely, brightness produced by a luminous intensity of one lamp on a white surface at a distance of one metre. This brightness would be very nearly equal to a Carcel-metre, originally named a Lux by Sir W. H. Preece, and to that which we call *one candle-foot*, a convenient illumination for the purposes of vision. The candle-metre or Bougie-metre christened by the 1896 Congress one Lux is too small an illumination to take as a standard. An illumination of one lux on a printed page is not sufficient to enable us to read. It is about the illumination given on a newspaper in the hands of an unfortunate traveller in a railway carriage illuminated by one of the miserable oil lamps still in use on some lines. The least comfortable illumination for discriminating print is one 10 times as great as that called by the 1896 Congress *a lux*. The practical photometerist hardly ever feels the need for other units than those of luminous intensity and illumination. In the suggested nomenclature the unit called the *lamp* would be the name for the first, and the *lamp-metre*, which might also be called a lux if desired, would be the unit for the second.

If the Violle platinum standard should be ultimately adopted as the final standard of reference in Great Britain, the *lamp* might be defined as that light given out normally from half a square centimetre of the surface of platinum at its melting point. It could be reproduced or recovered at distant places by the use of a Harcourt pentane argand lamp, or by the use of one of the large bulb electric glow-lamps taking 30 watts.

[1] French, *La Lampe*; German, *Die Lampe*.

[2] Although so-called 5-candle lamps are much used in electric lighting, no difficulty would arise in speaking of these as *half-lamp power*, and the 2½-c.p. lamps as *quarter-lamp* power.

Again, why do we still adhere to that rather absurd method of measuring what is called the "efficiency" of an electric lamp by stating the *watts per candle?* This so-called efficiency is greater the less the number by which it is defined. We ought rather to specify this quantity in *lumens per watt or per kilowatt.* In lumens per watt the efficiency is a number near to 4 for a glow-lamp and 12 for a continuous-current arc, and these numbers give us at once some idea of the relative economy in working. We prefer, however, apparently to travel along old intellectual grooves rather than strike out for a new and better way.

A more important matter, however, than the reorganisation of nomenclature is the actual establishment in England of a primary reference standard of light. At present there is no Court of Appeal in case of disputes as to the so-called candle-power of glow-lamps or arc-lamps. Without presuming to dictate a course of action, it is much to be desired that this matter should engage the attention of the National Physical Laboratory without delay, and that a careful re-investigation should be made of the Violle platinum standard, and at the same time the Lummer and Kurlbaum platinum standard as adopted by the Reichsanstalt should be examined. Also experiments should be undertaken to see how far the large bulb glow-lamps made on the plans suggested by the author can be employed as a means of distributing or reproducing this standard in distant places.

The Hefner lamp has rightly never been accepted in Great Britain, as it is not a suitable practical unit for electric photometry, but if the platinum reference standard could be set up at one or two places, and if it could be shown that the light from one square centimetre of molten platinum is practically represented by twice that given by a Harcourt pentane lamp, or by a certain glow-lamp made and used in a certain manner, the difficulties which beset photometry at the present moment from the want of a common recognised standard would be diminished. It is unfortunate that national feeling seems to enter into this question of the selection of standards of light. No sooner is one practical unit suggested in France than a different one is adopted in Germany and a third in England; but that is no reason why the whole question should not even now be re-examined *ab initio* by photometrical experts with the object of settling an International Unit of Light, and obtaining for it universal acceptance as in the case of the International Electrical Units.

These suggestions are thrown out not in any dogmatic spirit, but as the result of nearly twenty years' experience in the testing of electric lamps, and in the hope that they may stimulate discussion and enable the members of this Institution to formulate their experience and opinions on the photometry of electric lamps.

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Mr. Vernon Harcourt.

Mr. A. VERNON HARCOURT: It is very difficult to be called upon to make remarks upon this paper, because of the great amount of matter that has been brought before us, and the great variety of materials. Perhaps I may take what is the main subject of the paper, namely, the photometry of the electric arc. Many years ago I took part in the photometry of arc lights in connection with an investigation made by the Elder Brethren of the Trinity House into the value of various sources of light placed behind lighthouse lenses. There were set up at the South Foreland some temporary lighthouses, in one of which the source of light was an oil-lamp, in another a gas-lamp, and in another an electric arc; and these were piled one upon another, so that there were three or four tiers, in order to produce the most powerful light possible. The object was to test the value of these different lights in different kinds of weather. Thus the inquiry extended beyond the matters which have been dealt with to-night, but it involved the photometry of the various lights, by themselves or as seen through lenses, on clear nights as well as on hazy nights. There was not found to be any insuperable or even great difficulty in arriving at a comparison between

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the arc lights and the large flame lights. The measurements were chiefly made at a considerable distance. The Trinity House provided some huts for making measurements at distances of one, two, and three miles from the lighthouses, and the beam of light sent from the several holophotes could be thrown upon them.

The point, however, to which I wish to refer is that it was found possible to arrive at a fairly accurate estimate of the value of the arc light by itself, and as shown through lenses, by means of a Bunsen photometer, in which in place of a plain opaque disk with translucent margin a translucent disk with serrated rim and opaque margin was used. This small difference greatly facilitated the estimation of the illuminations produced by the distant arc light on one side and the one-candle pentane flame a few feet off on the other. The appearance of the two illuminations was, of course, exceedingly different, but I found it was possible to make the comparison by fixing attention upon the degree of distinctness of the central figure, the star, against the background, and that it was not difficult to do this without being distracted by the difference of colour. On one side was seen a blue star upon a pink ground, on the other side a pink star upon a blue ground. I had a good opportunity of trying the general practicability of this comparison by asking a number of the mechanics and other servants of the Trinity House—men not practised in photometry, but intelligent men with good eyesight—to place the photometric disk in succession. The direction given them was to bring the disk to such a position that the stars on the two sides as seen against the background, should have an equal, minimum, distinctness. If the disk were moved thence a little to the right or to the left the star of one or the other colour stood out more clearly, and it was not difficult by sliding the disk-holder to and fro to arrive at a position in which the distinctness of the pattern was equal. The photometer was so arranged that the observer for the time being could not himself see what the reading was, but another man read the scale on the opposite side of the photometer, when directed to do so, and wrote the figures down without saying a word. In this way of working there was no possibility of self-delusion and of an artificial consistency, such as happens especially with a photometer where the disk is moved by a winch. It was found that the results of observations so made showed a very fair amount of agreement; I do not remember what the percentage error was, but it was not large.

The mention of moving the disk backwards and forwards reminds me of what I was shown some years ago by Sir William Abney, who pointed out that a good judgment may be made between lights of different colours by using a comparatively large oscillation. Certainly we have, apart from our perception of different colours, an impression of brightness; we can be quite sure that a very bright green light is brighter than a dull red light, or *vice versâ*. Beginning with rather large oscillations of the disk-holder and gradually diminishing their amplitude we can arrive at a middle point representing equal illuminations. The colour difficulty may also be overcome by using very low illuminations, such as that of one candle at a distance of eight or ten feet. In the dusk the leaves and petals of a scarlet geranium

can scarcely be distinguished by colour, though their forms are still quite visible. So it was with the illumination of adjoining strips of the photoped by a one-candle flame ten feet away, and the beam from the lighthouse arc at a distance of two miles.

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I should like to say, in conclusion, that this paper appears to me to be one of very great interest. I have listened to many papers on different points in photometry, but never to so complete an account of the subject as we have had the pleasure of hearing this evening.

Dr. Glazebrook.

Dr. R. T. GLAZEBROOK: I should like to re-echo what has just fallen from Mr. Vernon Harcourt as to the extreme interest and value of the paper to which we have listened. I feel that Professor Fleming should be thanked very cordially for having brought this matter before us in so clear and interesting a manner, and I think the Institution is to be congratulated in having such a paper laid before it. I have a particular reason for being grateful to the author for the paper, because he has called attention to the important work on the subject that still remains to be done, and has made suggestions of great interest and value on various points as to how that work may be taken up by the Institution which I direct. I say I have reason to be thankful because, although it is the fact that so many suggestions in regard to work which may be undertaken by the National Physical Laboratory have been made that I fear it will be long before we can carry them all out, yet I am glad to have suggestions made, in order that I may go to the powers that be with a still stronger case to prove to them the utility and necessity of that Institution. However, with regard to photometry we are perhaps in a better position than we are with regard to some other questions, because, although we have done nothing as yet, we are, thanks to the generosity of Sir William Preece, Mr. Trotter, and some others, before long to be equipped with a very complete set of photometric instruments and appliances, and then I hope we shall go into the question thoroughly and completely, and standardise lamps for the users as is done in Berlin.

There is very little to criticise in the paper. With most of it I agree very cordially indeed. It struck me on looking it through that possibly the position that Professor Fleming gives to the Vernon Harcourt 1-candle pentane standard in comparison with the Hefner or amyl acetate lamp was not one that would be assigned to it by all writers on photometry. If one takes the figures which Professor Fleming gives in the paper, it appears, for example, that the effect of change of barometric pressure on the Vernon Harcourt 1-candle flame standard is four or five times as great as the effect of similar changes upon the amyl acetate lamp. That in itself seems to me to be a difficulty if one wished to criticise or discuss exact details. I should say further with regard to the 10-candle pentane lamp that I am not quite sure from the paper if the question of the effect of change of atmospheric pressure, moisture, the presence of carbonic acid, and so on, has as yet been examined in the same detailed way as it has for the amyl acetate and for the 1-candle pentane lamp. I think I am right in saying that that examination has not been made so completely, and that it is one of the pieces of work we may well take up in time.

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I was more especially interested in what Dr. Fleming told us about the possibility of arriving at an incandescent standard of light, and in particular to the reference he made to the recent and very valuable and important work of Mr. Petavel. I have read that work with very great care, and I value it very highly; indeed, I hope in a few moments to bring before the Institution some of the more recent developments of Petavel's work, which I think have added greatly to its value. At the same time I am inclined to think that Mr. Petavel is a little too sanguine in the expression of his opinion as to the possibility of realising the Violle standard. He succeeded in doing that, though with great difficulty, by means of the precautions that are described in his paper. I should have been more hopeful had he succeeded in melting his platinum by means of an electric current. But he found difficulties in using the electric current to melt the platinum, and had, in consequence, to have recourse to a very careful mixture of oxygen and hydrogen, using the oxy-hydrogen blowpipe. There are, however, one or two methods in which we may hope to use the surface of incandescent platinum, made to incandesce by means of an electric current, as a satisfactory standard. If we are to use any incandescent surface there are two conditions that we must satisfy. In the first case we must have a surface which always, for a given temperature, emits radiations exactly the same, both in quality and quantity, and, secondly, we must make sure that the temperature of the surface which is radiating light to us remains the same throughout our observations. Those are the two conditions that I think Prof. Fleming lays down, and which have to be satisfied. I take it that the first condition can be satisfied satisfactorily if we use platinum or one of the metals of the platinum group. Mr. Petavel has recently been making experiments with iridium, platinum, and some other metals of that group with, I think, more satisfactory results than with pure platinum. I notice, however, in the last number of the *Thätigkeit* of the Reichsanstalt, an interesting account is given of the method which a carbon surface is raised by electricity to a high temperature to serve as a standard source of radiation (it is described in *Engineering* of October 31st last).

With regard to the second condition, there are various ways we may use to determine whether the temperature of the surface which we are employing as our radiator is definite in amount when we are employing it. One of these is the method which has been referred to in the paper by Dr. Fleming, the method of Lummer and Kurlbaum. It is well known that the proportion of light absorbed by any given material of a given thickness (say a cell of water two centimetres in thickness) varies with the temperature of the radiating source. Therefore if you can raise the temperature of your radiating source until a certain definite proportion of its radiation is absorbed, you know that the temperature of that source is definite. Of course, in realising that, which is what Lummer and Kurlbaum have done, you have the difficulty of measuring a 10 per cent. absorption, of making sure that the two sources of radiation which you are comparing in your apparatus differ by 10 per cent. There are, however, other ways

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of realising the same result. The intensity of radiation differs in different parts of the spectrum, and the curves of radiation for the red and the violet parts of the spectrum are different. So that if you separate the radiated light from your source into two parts, by passing it through a spectroscope or otherwise, and if you isolate the radiations from the red and from the violet ends of the spectrum thus formed, and examine how they vary with the temperature, you will find that while for low temperatures of the radiating body the radiation from the red end of the spectrum is the greater, yet as the temperature of the source increases the radiations from the violet end of the spectrum become the greater, and for one definite temperature of the source the radiations from the violet end have the same intensity as those from the red end of the spectrum. The two curves which give you the relation between radiation and temperature cross at one point, and that point gives you a definite

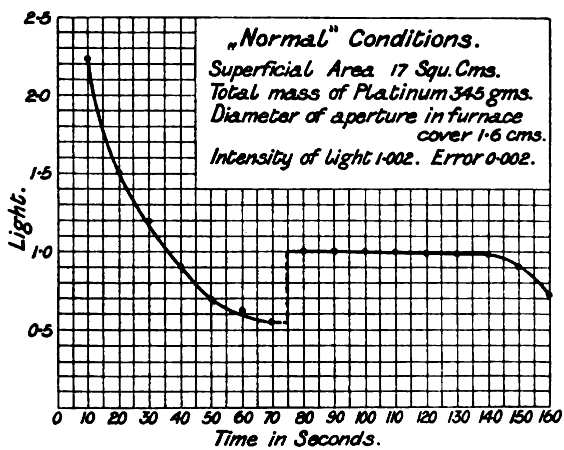

FIG. A.

temperature for your radiating source. That is a method which has been used by various investigators, and is used now at the Reichsanstalt. The objection to that method is that the two curves of radiation are very steep to the vertical axis, so that the point at which they cross cannot be determined with very great accuracy. But there is another method which can be used, the method which has been used lately by Mr. Petavel, and by means of Mr. Petavel's slides, which I will throw on the screen; I can explain the matter to you in a few moments.

Fig. A illustrates the normal results of an experiment on the intensity of the radiation from incandescent platinum. The curve gives the intensity of the illumination at intervals of ten seconds from a mass of incandescent platinum near its melting-point. I need not go into the details of how the curve is obtained, but you will see that starting ten seconds or so after the experiment begun there was a considerable luminosity, nearly 2½, in certain units. That luminosity

Dr. Glazebrook. dropped very rapidly, and after 75 seconds had elapsed it suddenly rose again through a number of units from 0·5 to 1. At that moment the incandescent platinum began to solidify and then for some little time afterwards, from 75 seconds to perhaps 120 seconds, the intensity of the illumination remains practically constant and at what he calls the one unit. But in order to get that you have to repeat very carefully and exactly the conditions under which Mr. Petavel worked; this curve shows the result of one of his most successful and satisfactory experiments.

Fig. B gives the results of experiments on the comparison by means of two thermopiles of the light from the red and blue ends of the

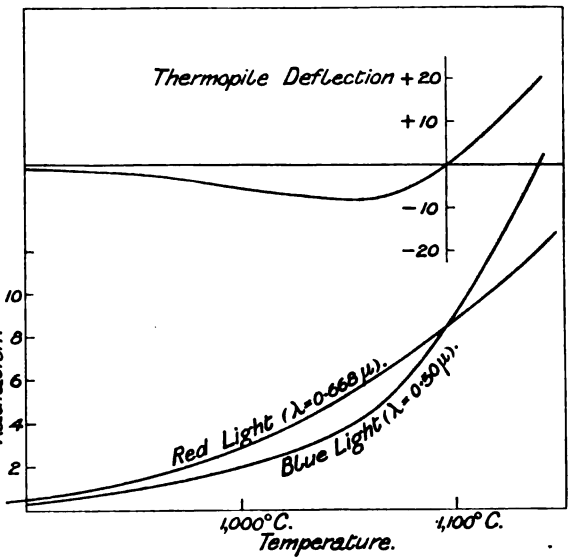

Fig. B.

spectrum. The light from the red end falls on one thermopile, and the light from the blue end falls on the other. The two thermopiles are connected in opposite directions through a galvanometer, so that its deflection measures the difference in the intensity of the two radiations. The red light alone causes a deflection below the zero line, and the blue one above. The resultant thermopile deflection is shown in the top curve. At first, in consequence of the fact that the red light is the stronger, there is a deflection downwards. The deflection increases and then gradually decreases, and when you come to the temperature of just under 1,100° C. the galvanometer deflection is zero and the radiation for the two ends is the same. That marks a definite temperature of the radiating source, and the total radiation emitted when this temperature is reached might be taken as your standard of light.

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The horizontal distances (Fig. C) give the scale of temperature, 1,000° C., 1,100° C., and so on, and the vertical ordinates give the percentage of radiation that is transmitted by various thicknesses of water, benzene quartz, glass, and other substances. You will notice in all cases that as the temperature rises from 1,000° C. to 1,700° C. in those various curves, the percentage of light transmitted increases.

Fig. D gives exactly the same curves for some other materials. The percentage of light transmitted as the temperature rises is shown as increasing in the case of all substances except one light, black fluorspar, the curve for which comes downwards across the diagram in the opposite direction to that of the others. So that if you cause the light from a radiating body to be divided into halves and transmit one half through water and the other half through black fluorspar, and if you allow each half to fall on a separate thermopile, then as the temperature rises the thermopile connected with the water will rise in temperature, that connected with the black fluorspar will fall in temperature; and there will be a definite temperature of the radiating body, dependent on the thickness of the water and of the black fluorspar—1,360° C. in that diagram—at which the radiation from the black fluorspar is equal to the radiation from the water. If we can determine that, then it will enable us to keep our radiating body at a definite temperature, and then if we measure the limit emitted at that temperature we can treat the source as a standard of radiation.

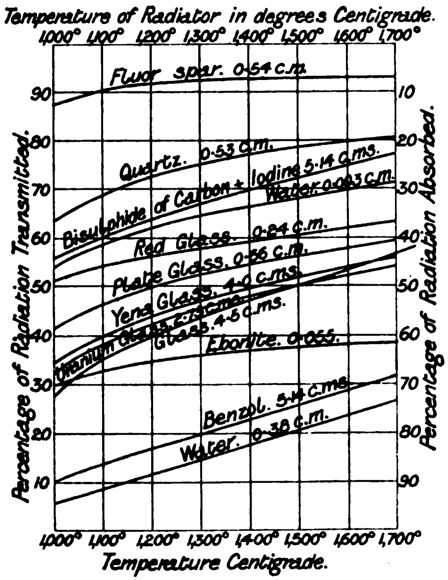

FIG. C.

In Fig. E the arrangement of apparatus is shown diagramatically. To the left is the radiating body R. The source of light is split into three portions. The central portion passes on to A, and can be compared against a standard candle, the pentane lamp, or whatever is suggested. In the upper part of the diagram the stream of light is allowed to fall through a screen of water on to a thermopile P 1. The lower half of the diagram shows the light falling through a screen of black fluorspar on to the thermopile P 2. Those two thermopiles are connected oppositely through the galvanometer G., and you know that so long as the needle of the galvanometer is at zero the temperature of

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your radiating source is definite in value. That is a temperature which with the same piece of apparatus can always be reproduced, and such a radiating body radiating at that definite temperature can be taken as the primary source of radiation. Such an arrangement seems to me, as far as I have studied the subject, to hold out very considerable hopes for success, and to open the possibility of obtaining a primary standard of radiation which shall be superior to the original Violle standard, and, I hope, in many ways to the Lummer-Kurlbaum standard used in Germany. I think Mr. Petavel deserves great credit for his work.

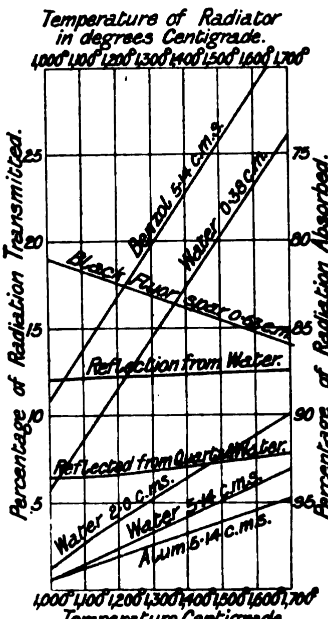


FIG. D. (*see p.* 177).

There are many points in the paper to which I should like to refer, but I think I have said all I specially wish to say by calling your attention to this recent work of Mr. Petavel's, which was laid before the British Association at Belfast, and which has not, I think, been noticed very fully in the scientific Press.

Sir Wm. de Abney.

Sir WILLIAM DE W. ABNEY: I will only deal with that part of the paper with which I am most accustomed, namely, what we may call colour photometry. The various methods which have been shown to us, such as the flicker photometer and another photometer whose name I forget, do not, I think, measure the illumination. They go a degree towards it, but they do not measure the brightness of the light. The only way in which you can measure the brightness of the light is to place the colours side by side and judge when they are of equal brightness. That is the method which I have been accustomed to use for a great many years now, but apparently it is not as well known as it might be. It is an excessively simple method. A red and green light can be matched together just as readily as two white lights of the same colour can be, provided you use the oscillation method. The error of observation becomes very small with practice. It may be asked what the proof is that what you are measuring is the brightness (or luminosity) and not something else. I will prove it in this way. Supposing I wish to compare the brightness of two spectrum colours, one, say, in the red near the place of the red lithium line, and the other a green near the magnesium line. Slits placed in the spectrum at those particular parts will pass rays which, combined together, will form white. By opening or narrowing the slits a patch of white light can be thrown on a screen by my colour patch apparatus which cannot be distinguished from the white of the comparison light.

Sir Wm. de Abney.

I may say that I use the crater of the positive pole of the arc light for the light to form the spectrum, and I use the whiteness of that light for the purpose of comparison. The mixed rays forming white on the screen, a patch of white light from the comparison light is thrown over it, and a rod, as by the ordinary Rumford method, casts two shadows side by side. By means of sectors the shadows are equalised, and the angle of the sectors read off. The green light is covered up, and we have a red alongside the white. Again, by means of sectors, which have movable apertures whilst rotating, the white is made brighter or darker alternately than the red. There is some point between those two in which the white is neither too light or too dark in comparison with the red, and by gradually diminishing the oscillations you come to a point in which there is no flicker whatever, no winking. The two shadows seem to wink at you after you pass the neutral point, but there

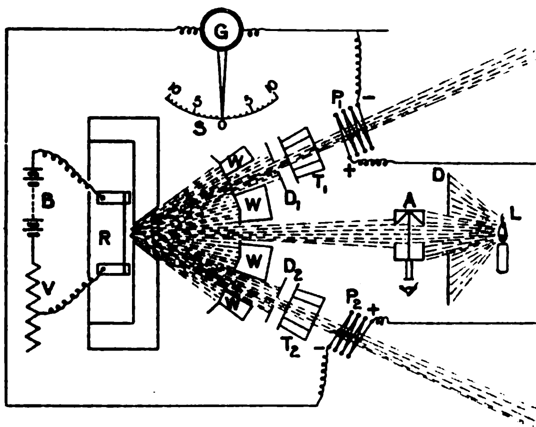


FIG. E. (see p. 177).

is a point where the winking ceases altogether, and this is the point where the sector shows equal brightness. You read the sector off, and you say you have got so much—30°, say, of the white. The red is shut off and the green is placed against the white, a measure is again made, and we get a certain angle, say another 30°. If the two happen to be 30° each, you will find that the white light is 60°. You may go right through the spectrum in the same way, and you will find that is the case—the sum of the measures of all the different components is equal to the measure of the lights combined. That is a very important point. If it does not mean the measurement of brightness, what does it mean?

There is one other point on which I should like to remark, and that is the question of white light. Everybody looks askance at you when that question is put. There is, however, a physiological white light which has a very definite whiteness. I do not know whether the audience is aware that they are all colour blind at parts of their retina, but it is a fact. Everybody is more or less colour blind. I do not say that they are colour blind through the whole of the retina,

Sir Wm. de Abney.

but there are portions of the eye which are absolutely colour blind; they can see no colour whatever. If I had a spectrum apparatus I could show it in a minute. If you take a spot of green light and look at it with the centre of the eye, you will see that it is green, but as you move your head, and your eye with your head, you come to a point at which you see no colour whatever on the part of the retina on which you receive the image; the green has gone, and you see a pure white light. Whatever colour you take, that colour will always give the same quality of white light throughout. This is what I call the physiological white light. The white light of the crater of the positive pole is very nearly uniform with that, as we can tell by comparing the two. My standard of white light is what I call the physiological white light.

To go back to the subject of photometry, Prof. Fleming mentioned Purkinje's phenomena. That is a phenomenon which was measured qualitatively by him, but I think if he will refer to a paper which I had the honour of reading before the Royal Society a good many years ago, he will find not only the Purkinje's phenomena set forth, but the absolute details as to where every ray commences to bend and where it takes its normal course and becomes a straight line with different intensities. There is a point where every ray becomes a straight line; the starting-point or zero of the red is different from that of the blue, and the blue from that of the green. The stimulus required to give a sensation of colour is greater in some than in others. The zero points are not the same. But this difference in zero points only need be taken into account when the lights to be measured are, comparatively speaking, feeble. You have not to pay great attention to that phenomenon when you are measuring lights of the ordinary brightness; it is only when you come to low luminosities that you need take it into account at all. The fact that you have moonlight in which there is practically no red is one effect of the difference in zero points, and moonlight is only dim sunlight.

There are one or two other points that I should like to mention. This method of distinguishing lines is not a method of measuring the brightness at all; what is measured is the acuteness of vision in some particular colour. Acuteness of vision is a very different thing to brightness. The acuteness of vision in the yellow is very much greater than the acuteness of vision in the blue. Of course there are reasons for it. The accommodation of the eye is different for the blue from what it is for the yellow or for the red. One of the supposed measurements of luminosity of the different rays of the spectrum was published by Professor Langley of the United States. He obtained his measures by reading logarithmic tables in the spectral colours. When he could no longer see what the figures were on a particular page of logarithms by dimming the light, he noted the point. He went through the whole of the spectrum in this way, and from it plotted a luminosity curve of the spectrum. What he had plotted was really an "acuteness of vision" curve. The acuteness of vision curve which was derived from the log readings would also be derived from noting the disappearance of the ruled lines of different fineness which the author employs. I am endeavouring to indicate

Sir Wm. de Abney.

some of the difficulties we have in colour photometry generally. I am not talking about the ordinary intensity photometry, but only where you have delicate photometry to do. I do not suppose anybody has realised the fact that if you have a white paper spot an inch in diameter, and another a $\frac{1}{4}$ inch in diameter, and place them on a black background, say, three or four inches apart, the big inch spot is considerably brighter than the $\frac{1}{4}$-inch spot. Although you have cut them out of the same paper they will be of a different brightness. If you take colours the same thing happens. Supposing you have two patches of spectrum colour of red $\frac{1}{4}$ inch in diameter and another an inch in diameter. If you stand three or four feet off the brightness is different. It shows that when you are dealing with photometry of a delicate nature you have to take into account all the phenomena and all the deficiencies which exist in the eye. It may be said regarding the two white spots that the yellow spot of the eye would account for that occurrence. It might in a certain sense, but it will not account for the difference in intensity of the red spots, because the yellow spot of the eye allows all the rest of the red to go through without any absorption whatever. The flicker photometer comes under the same ban, to my mind, as the other. Flicker photometry is based on a physiological fact, the persistence of vision after the stimulus has been removed, and it does not give the same curve as the ordinary brightness test. Prof. Draper of New York, I think, was the first to measure coloured light in that way. I was in commuication with him at the time he was making those observations and when he published them. After comparing them with the other methods one came to the conclusion that he was measuring some form of acuteness of vision. I think you have to be very cautious to show that acuteness of vision is equivalent to brightness of light. What is the difference between gas-light and electric light? You may say the one is whiter than the other. No doubt that is quite true, but do you know how much that whiteness is due to the blue? The blue sensation of the electric light is about $\frac{1}{100}$th part of the red sensation in the arc electric light; you may cut off the blue sensation if you like, and it will give you a difference in luminosity of about $\frac{1}{200}$th part of the whole, so that you can very nearly reduce the arc light to the colour of an incandescent light by suitable means and without very greatly damaging your measurements.

The subject of the paper to-night is very wide; and when one has lived among photometers for so long as I have, one has much to say. There is another method by which very accurate methods of ascertaining the brightness of a light can be obtained, and that is by extinction. If you have a suitable absorption apparatus and a suitable medium you can totally extinguish the light reflected from a surface, though radiation is still passing, but of course proper precautions must be taken as to how you use your eyes. You have to keep in the dark for some considerable time, and by that means you can get a very good measure of the brightness of any light by knowing the amount of absorption that has to take place in order to extinguish it. That was one of the first methods I adopted in some War Office experiments undertaken some thirty years ago when the

Sir Wm. de Abney.

electric light was being introduced into the service. I was then charged with this branch of work at Chatham, and I was called upon to measure the intensity of those lights. At that time I came to the conclusion that the extinction method was perhaps the best method extant. I do not say it is the best method now, but at that time I had the available apparatus, and I measured the lights by that means with very great ease. Finally, let me say I do not see the slightest difficulty in comparing even, let us say, a smoky railway lamp with the arc light; it is simply a matter of practice. If you have been doing the work for some time you never, or very rarely, make a mistake. Anybody who has worked at colour photometry seldom fails in measuring correctly lights of totally different colours. I prefer myself to have a neutral comparison light (a colour intermediate between the two taken to be compared) for getting the closest readings. White for general work is a neutral colour, and that is why it should as a rule be used.

The President.

The PRESIDENT announced that the scrutineers reported the following candidates to have been duly elected:—

Member.

Arthur George Way.

Associate Member.

Geo. Frederick Alexander Norman.

Associates.

Horace Bourne.
Frederick Bruce.
Francis James Humphrey.
Robert F. Morris.
Fitzroy Owen Jonathan Roose.
J. Charles Serjeant.

Student.

Maurice George Tweedie.

The Three Hundred and Eighty-fourth Ordinary General Meeting of the Institution was held at the Institution of Civil Engineers, Great George Street, Westminster, on Thursday evening, December 18th, 1902—Mr. JAMES SWINBURNE, President, in the chair.

The minutes of the Ordinary General Meeting held on December 11th, 1902, were read and confirmed.

The names of the new candidates for election into the Institution were announced, and it was ordered that these names should be suspended in the Library.

The following transfers were announced as having been approved by the Council :—

From the class of Associates to that of Associate Members—

Thomas W. Bloxam.
T. W. Broadbent.
Archibald Campbell.
Wm. Leonard Carter.
Thomas Cooper.
Lieut.-Col. J. H. Cowan, R.E.
Arthur Charles Devey.
Edward Dixon.
Edward G. Fishenden.
Urban B. Gilbert.
John Geo. Holdsworth.
Arthur Llewellyn Lean.
Henry Luttrell-Elward.
Joseph Roper Penning.
Frank C. Porte.
George Robertson, Jun.
J. M. Shackleton.
Henry George Shoolbred.
William Sillery.
Alan Smout.
Frederick Soloman Spiers.
Ernest F. Szlumper.
Edward Ernest Tasker.
Robert Tervet.
Frank Charles Thomas.
G. Thomas-Davies.
Herbert E. C. Tutte.
Frederick M. Walker.
William Walker.
Frank Wallis.
Charles T. Walrond.
John A. Walter Ward.
Burkewood Welbourn.
Charles F. Wilkins.
C. H. C. Woodhouse.
Ernest H. Wright.
John Ortelli Zerega.

Messrs. C. W. Barnes and R. W. Hughman were appointed scrutineers of the ballot for the election of new members.

RESUMED DISCUSSION ON PAPER ON "THE PHOTOMETRY OF ELECTRIC LAMPS" BY DR. J. A. FLEMING, M.A., F.R.S., MEMBER.

Mr. A. P. TROTTER : The paper before us is, I think, the first we have had in this Institution on the question of Photometry. We had a paper on A Photometer, the discussion upon which turned largely upon the abused and moribund Standard Candle. The subject of photometry has occupied the attention of a very few other scientific Mr. Trotter

Mr. Trotter. societies, but there was one most important Physical Society paper by Prof. Ayrton and Mr. Medley in 1895, which was the first publication on the rise and subsequent fall of candle power of glow-lamps as they age. Beyond that very little indeed has been done, but the subject is, I think, very well worthy of attention, considering the large proportion of the electrical industry which is employed in simply producing light.

The first part of the paper deals with the standards of light. If I criticise the pentane lamp, it is purely from the point of view of the electrical engineer. I should have liked to hear, and perhaps we may still hear, the opinions of the gas referees upon the subject. At all events, I would like to know whether the various errors to which this lamp is subject cancel out when a gas flame is compared with it; I imagine they do. I suppose gas engineers do not care very much about the errors due to carbon dioxide in the air, or to the humidity. But there is a rather important variation, something to be corrected for, to which Dr. Glazebrook alluded on the last occasion, that due to the barometric pressure. It was very evident that a lamp depending for its supply of fuel on the gravity of the heavy vapour falling, must vary a good deal with the barometric pressure, and the variation is something like four and a half times as much as that of the Hefner lamp. The Hefner lamp, on the other hand, has met with considerable criticism from Dr. Fleming, but I think it is not quite so bad as he suggested. I used this lamp in photometry with which I occupied myself nearly ten years ago, and I consider it to be a very useful and practical standard, its most serious disadvantage perhaps being its colour. Dr. Fleming, perhaps, is not quite logical when at one moment he said the colour was so bad that it was impossible to use it, and a little later said the Flicker Photometer so completely got over the colour difficulty that he could easily measure an arc lamp against a candle. If that is the case, the objection disappears. I have brought down my lamp to show you. The mode of measuring the height of the flame is rather different from the one shown by Dr. Fleming. This has the Krüss optical flame gauge; it is a little camera, with a lens and a ground glass screen, and on it is a line for the standard height of the flame, 40 mm. There is a gauge supplied with it for gauging the height of the top of the wick-holder, and a point 40 mm. above it. The only difficulty I found was with regard to the purity of the amyl acetate. Certainly it will not do to buy the amyl acetate at any chemist's shop any more than you can buy the pentane at any chemist's shop. It is best to buy it from the makers of the lamp, but I find that even the official quality corrodes the brass work a good deal, so I added a little tap to run it out when the work is over. It is a good thing to wash the lamp out with alcohol before putting it away. The flame has a singularly low temperature. I suppose this accounts for the reddish colour, and for the small draught. The flame is therefore easily disturbed and must be protected from draughts.

On pp. 129, 130 some formulæ are given—rather foggy formulæ, I am afraid. The first one deals with the quantity of water vapour. That need not concern us very much. The wet and dry bulb thermometer

is good enough, but the variations are not very great and can be allowed for approximately. The next one is the carbon dioxide in the air. That is practically negligible in the ordinary laboratory. Dr. Fleming mentions how it was noticed when a good many students came into a small gallery where a 10-candle pentane lamp was being used; but you do not get much carbonic acid gas in an ordinary ventilated room, using electric lamps and a Hefner lamp. Liebenthal's formula $L = 1{\cdot}012 - 0{\cdot}0072\,x$, where x is litres of carbonic oxide per cubic metre, assumes a unit value for the light when these are 1·66 litres of carbonic oxide per cubic metre, or in plain English 16·6 parts in 10,000, or in still plainer English an extremely stuffy and unhealthy state of the air. One of the most important of the formulæ is the one relating to the height of the flame. I will put another formula of the same class on the board— Mr. Trotter

$$P = \left(18 + 1{\cdot}5\ (n - 12)\right).$$

P is the price in shillings per dozen of lamps: the formula simply means eighteen shillings a dozen. I say that that is not the right sort of thing to offer to engineers, although it may do for the laboratory. I do not blame Dr. Fleming for contriving it, only for reproducing it. Dr. Liebenthal is responsible for it. The long and the short of that very foggy formula is, that the height of the flame is proportional to its candle-power when it is over 40 mm. I attach great value to Liebenthal's work on the Hefner lamp, but, nevertheless, I say that it is an abuse of mathematics to give us a formula of this sort.

The height of the flame which will give us one candle-power is rather an important matter, and Dr. Fleming gives 0·88 as the multiplier, being the average of a number of measurements. I have used 0·877, the average of a different set, but I always think of the relation as a difference of 14 per cent. and not as a fractional multiplier. Dr. Fleming's figure works out at 13·6 per cent. I think that until an authoritative comparison is declared, 14 per cent. is as close to the mark as 13·6 per cent. On this little ground-glass screen I have drawn another line 5½ mm. below the official black line, and this gives me the height of the inverted image the flame which corresponds to one British standard candle for all practical purposes. The Standard Candle is now becoming an arbitrary unit embodied in the pentane lamp, and this, whatever be its defects or merits, must be accepted of course as the official 10 Standard Candles, and we shall base any standard lamps upon that and not upon the measurements with actual candles, which have had their day. This formula is an important one; Dr. Fleming gives it correctly, but I think this is a good opportunity to call attention to the fact that in Palaz's well-known book on photometry it is given with two misprints, and these are reproduced in the American translation of Palaz's work. I did not read Palaz until after I had stopped my photometric work, and I used to work with the 14 per cent. Palaz does not quote from the original paper, but from *La Lumière Électrique*.

Dr. Fleming's standard lamps with aged filaments put into new globes

Mr. Trotter. is certainly an admirable idea. But there is one point about them which does not satisfy me, and that is the use of a clear-glass globe. I have found, in using a glow-lamp as a working standard, that it is extremely important to have either a ground-glass bulb to the lamp or a ground-glass shade; because not only do very small irregularities in the glass produce very considerable refractive effects, and the very smallest movement of the lamp makes a very considerable difference if you are dealing with anything like 1 or 2 per cent., but you have an imperfect concave reflector at the back of the lamp which has no particular focus. I do not think it is sufficient to say you should use a lamp in a definite direction. I have always used a ground-glass lamp, taking care to handle it by a flange attached for the purpose to the socket. I think perhaps a ground-glass cylinder which can be cleaned carefully with ether to make it perfectly clean, is better still, and if it is regarded as a part of the standard no correction need be allowed for the absorption of it.

The photometer to which Dr. Fleming is most attached is the Lummer-Brodhun, which calls itself in the advertisements a precision photometer. I rather object to any photometer calling itself a precision photometer. It has the disadvantage to many English people that you have to put your eye against an eye-piece. A German scientific man is never happy unless he has his eye glued against an eye-piece, and I think Sir William Abney agrees with me that in photometry you want to take a general good view at a thing, standing some way off, and forming a judgment, because after all photometry is almost entirely a question of judgment. Photometry is not a physical measurement; it is a judgment, and you must base your physical measurement indirectly upon the judgment of the eye. Dr. Fleming also alludes to various other photometers. We do not hear much about the Bunsen photometer now. Many text-books on physics make the extraordinary error of thinking that a disappearance on a Bunsen screen means a balance. Mr. Stine, in a very good American book on photometry, gives a picture of the Bunsen photometer, with a plain disk erected on a bar with no mirrors. It is perfectly useless to put up a Bunsen screen, and to get the disappearance, and then say you have a balance. If you look on the other side you find the appearance is quite different. It is essential, in work with any photometer of the Bunsen type, to have two mirrors and regard the spot from the same angle by means of the mirrors.

In the next place Dr. Fleming goes in for the consideration of the dark-room and recommends an elaborate blacking of the photometer room. But I have found, working in an ordinary room, that you can do a good deal of accurate photometry by using black cardboard screens with holes in them, on the principle of the rifle range, of course putting your light in a black box. In my photometry work my most valuable assistant was a little piece of looking-glass. If I wanted to know whether there was any stray light falling on the photometer I screened the direct light with a small screen and placed the looking-glass so that I could look into it at an angle, and get, as it were, right into the photometer, looking from the photometer's point

Mr. Trotter.

of view to see if there was any stray light about. If there was not, I was satisfied that the effect was as good as if I had painted all the walls of my room black.

Dr. Fleming suggested a method of measuring the candle-power of an arc lamp which is not unlike the one described by Mr. Weekes in a discussion on a paper which I had the honour of reading before this Institution in 1892 on the candle-power of arç lamps. Mr. Weekes, like Dr. Fleming, took the horizontal beam as the standard. I think that is the worst beam to take, because with the smallest inaccuracy in the shape of the crater, or if it is a little bit on one side, the strength of the beam must be altered very seriously. The best beam to take would be somewhere about 45°, or where you get a full view of the crater. I have never tried the horizonal beam, but I say now, as I said in my criticism of Mr. Weekes' remarks in 1892, that it does not appear that the horizontal beam is a good one to take as a unit for comparison. I am very relieved to find a record of experiments showing the proportionality of the moving sector of a Fox-Talbot disk, because an American some eight years ago published a paper in the *Physical Review* making out that it was quite erroneous, and that the revolving sector did not cut off the simple proportion of the light, and that some physiological effect took place. It is a great comfort to find these results, because the bulk of Sir William Abney's work would have been valueless if it were true, and we are perfectly certain it is not, because Sir William would have been utterly confused years ago if the American suggestion had been true. Dr. Fleming goes on to discuss the polar curve of a lamp. I am very glad to see that in print in the Journal, because in my paper to which I have referred I made a bad mistake, and this puts it right. Dr. Fleming then goes on to say that before making experiments predetermined calculations of the illuminations of arc lamps should be made. I think that has been rather over-done already. Palaz's book is full of it; Blondel has done a lot of it; Maréchal, in his book on the lighting of Paris, has also investigated the matter, and I, in my paper read before the Civil Engineers in 1892, contributed a great many. We have been over-burdened with pre-determinations. What we want to do is to get actual measurements, of which I have done a few myself. Pre-determinations are interesting to calculate and plot, but as a matter of fact when you come to compare them with practice M. Blondel says they do not at all agree with the results. I concur, although I understand that M. Blondel made this remark in support of pre-determinations and in disparagement of plotted results of actual measurements. I will say, in conclusion, that I disagree with the objections to the candle and lux as units. The quantity 0·05 of a lux is a most important one in street work. The lux-second is an extremely important thing in photography—in fact, though hardly any one realises it, the whole question of photographic exposures is based upon the lux-second. All the arbitary plate numbers and constants of the Watkin and Wynne actinometers ought to be expressed in lux-seconds. It was "adopted" by the International Photographic Congress at Brussels in 1891, but so far as I know, is never used.

Mr. Trotter. I see no reason for disturbing the order of magnitude of the unit of luminous intensity. It is an effort to use this expression—luminous intensity, one would naturally say—candle-power. The expression candle-power is firmly fixed; nobody is going to talk of luminous intensity except in the lecture-room. To speak of a candle-power of one "lamp," meaning a candle-power of ten old candles, would be very confusing.

My appreciation of the Hefner lamp as an instrument does not bias me in favour of the Hefner unit as compared with the Standard Candle. Personally, I should be content to take the National Physical Laboratory declared value of the ten-candle pentane standard as ten British candles and use standardised glow-lamps or a Hefner lamp, with the National Physical Laboratory factor of 14 per cent. or whatever it is found to be. But the Hefner unit is established in Germany, and has

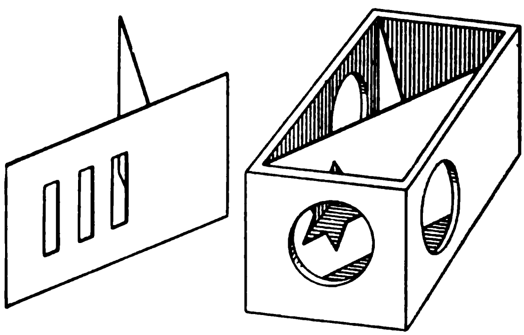


FIG. F.—Photometer box with star hole; and screen shown separately with slot holes. For the sake of clearness the holes are shown larger than in practice.

been accepted in the United States. To give up the old "parliamentary candle" and to adopt a new value would cause but little confusion and expense; and the old candle is not a standard of which we are proud. The arguments against abandoning or shortening the yard, and for adopting the metre instead, do not apply in this case. We cannot expect other nations to adopt the British candle. Lamp-makers ought to welcome the change, for 14 candle-power lamps will become 16 candle-power and 16 candle-power will become 18¼ candle-power.

A photometer which I described in a paper before the Physical Society in June, 1893, does not seem to be known. It achieves the result aimed at by the Lummer-Brodhun photometer in a much more simple way. In the Lummer-Brodhun instrument you see two images of the opposite sides of a screen. One image appears to have a hole in it, and you see the other image through this hole. To arrive at this result you have to use four prisms or two mirrors and two prisms. The prisms appear to be the latest improvement. These prisms have no less than eleven surfaces which must be truly plane and clean, and besides these there are one or two lenses. My photometer is

Mr. Trotter.

nothing more than a modification of Sir John Conroy's or Ritchie's photometer, and the modification is in the same direction as that made by Prof. S. P. Thompson. There are two screens set at the same angle to the light; one has a hole or holes in it, and you look at the further screen through the holes in the nearer screen. The angle of 45° alluded to by Dr. Fleming in various photometers is the worst angle, for if there is any glaze it will cause trouble, and to avoid all glaze is very troublesome. The best angle is about 35°. Not only may this angle be varied a little in either direction without causing much difference in the brightness, but the brightness is greater than at 45°. I see no object in using compressed magnesia. What if it be brighter by one or two per cent.? Shortening the photometer bar by an inch or two would more than do that. I have tried various materials, including screens painted with magnesia whitewash. I find that good Bristol board (white cardboard), with the glaze removed by a damp cloth or by pumice powder, is excellent. If one hole is used it may be star-shaped, distorting the star so that when seen at an angle it appears symmetrical. The edges must be carefully bevelled. Another form of screen has several slots which are used on the principle of limit gauges.

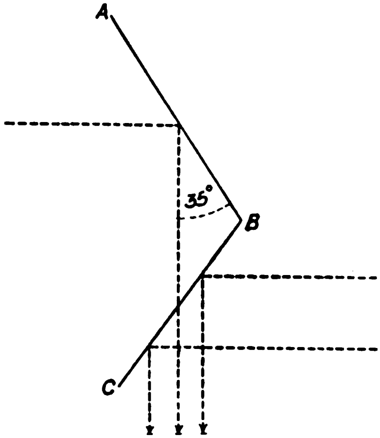


FIG. G.—Plan showing rays from the left striking the screen A B, part of which is visible through a hole or holes in the screen B C, which is illuminated from the right.

When the middle slot shows a balance the slot on one side is brighter and on the other side less bright. The back of the front screen should be blackened to avoid reflected light. The whole arrangement should be reversible to prove its symmetry, or to allow a mean to be taken. The instrument shown was made by Messrs. Nalder Bros. The method of double weighing recommended by Dr. Fleming, to get over want of symmetry in the photometer, is a poor comment on its construction.

In conclusion I offer four additions[1] to the valuable bibliography collected by Dr. Fleming.

Mr. Edgcumbe.

Mr. KENELM EDGCUMBE: It seems to me that the paper to which we have just listened is too good, too excellent a paper; that, in fact, it is rather disheartening to any of us who are rash enough to want to measure the candle-power of, say, our incandescent lamps. What are we to do if we have not such a palatial apartment as Dr. Fleming would have us set aside for a photometer room? Personally, I have

[1] [These are now incorporated in Dr. Fleming's Bibliography.—ED.]

Mr. Edgcumbe.

often had to work with the ordinary enclosed photometer, and I am very pleased to hear Mr. Trotter say that in his opinion good results can be got with one. I have certainly found the screen mentioned by Mr. Trotter to be most satisfactory; and this type of photometer, which I might perhaps call "the hole-and-corner photometer"—that is to say, a shelf, with a curtain in front of it—is certainly all the bulk of us can ever use. It has, moreover, several advantages over the photometer room. In the first place, we can read the divisions on the scale without any chance of seeing the lamps themselves, which is important; and, moreover, the instruments can be easily read.

In regard to one of the diagrams (Fig. 5), I should like to hear how Dr. Fleming proposes to regulate the voltage on what he calls the "comparison lamp." I take it, he uses another resistance, and measures the voltage on the potentiometer. This is a perfect arrangement if you have a 100- or 200-volt battery at your disposal, and which is not being used for anything else; but it is quite out of the question when working off the supply mains. For instance, you measure the voltage on one lamp to, say, one-hundredth of a volt, but by the time you have adjusted the other one, the voltage has gone down four or five volts. Moreover, for alternating currents, which are extremely useful for adjustment, and also for obtaining various voltages, you cannot use the potentiometer. If, on the other hand, the standard lamp is simply marked as giving such and such a candle-power at a definite voltage, it is merely necessary to connect the two lamps up in parallel across the same supply, and adjust roughly by the voltmeter. We know then that we have the same voltage on each lamp, and as it has been repeatedly shown that the candle-power bears a perfectly definite relation to the voltage, even with different types of lamps, it is quite immaterial how the voltage may vary, and the ordinary voltmeter is quite accurate enough for the purpose.

Dr. Fleming says that, in his experience, no voltmeter or ammeter is sufficiently accurate for photometer work. If used in the way he suggests, namely, by adjusting separately, I quite agree with him as regards the voltmeter, but as for the ammeter, I think it is amply sufficient, as a half per cent. or 1 per cent. error is quite negligible in photometer work.

I have lately been trying to do what, I fear, Dr. Fleming would consider impossible, namely, to measure the candle-power of ordinary incandescent lamps without any photometer room at all. I have placed on the table the instrument as it is at present constructed. It consists, as will be seen, simply of a box with two removable ends. One end is to be taken off, and the other has a hole cut in it. In the middle is a partition with the photometer proper—a grease spot. Stretched out to one side there is a tape, divided off directly into candle-power. In order to standardise the apparatus, you take the standard incandescent lamp, which gives, let us say, 16½ candle-power at 100 volts, put it on the mark representing 16½ candle-power on the scale, and move another lamp on the other side of the screen until you get a balance. Both lamps are run in parallel, and the instrument then becomes direct reading, it being merely necessary to replace the standard lamp

by the lamp to be tested. It has the advantage that it can be used anywhere—in this room, for instance. Stray light does not affect the accuracy of the apparatus, because when you are making the first comparison the light is there, and you are balancing with it. Mr. Edgcumbe

Mr. J. T. MORRIS: I propose to confine my remarks to the first portion of the paper, which deals with standards. Dr. Fleming divides these into two groups—primary standards and working standards. With regard to the former, having had the pleasure of seeing some of Mr. Petavel's work on the Violle standard, I can say that the colour of that light is very suitable for photometric work. In the amyl-acetate lamp, on the other hand, I consider that the colour difficulty does render accurate photometry more difficult, and for the primary standard of light one would naturally select one whose colour nearly resembles that of the light which one usually has to test. Mr. Morris.

Then, with regard to the setting up of the Violle standard, a large mass of platinum is required. Dr. Fleming mentions Mr. Petavel's statement that half a kilogramme is required. But that is a matter of over a pound of an extremely expensive metal. Further, the standard is one which, in the way Mr. Petavel used it, was only transient. The platinum was heated by means of an oxy-hydrogen flame to a high temperature, then the arrangement was allowed to cool steadily, and when it came to the temperature of solidification, there was a delay in the steady diminution of light from the platinum which lasted, in his case, for a period of about fifty seconds. Now, fifty seconds is hardly long enough for a primary standard of light to last. I would therefore suggest that it would be better, if such a standard is to be employed, to use electric heating by means of alternating currents. So long as one is dealing with secondary batteries there is considerable difficulty in connecting them in parallel for suitable working. But if an electric welding transformer were used for the purpose, I imagine more successful results could be obtained, only the current should not be cut off completely from the platinum. After the platinum is thoroughly melted the current should be reduced to such an amount that the platinum will, in time, completely solidify, and this will give a much longer time over which one can make observations of the actual light which is emitted during solidification.

Then, passing to the matter of working standards—and, I believe, by working standards Dr. Fleming means standards which are capable of something like one to a half of 1 per cent. degree of accuracy — I have had little practical experience with the amyl-acetate lamp.

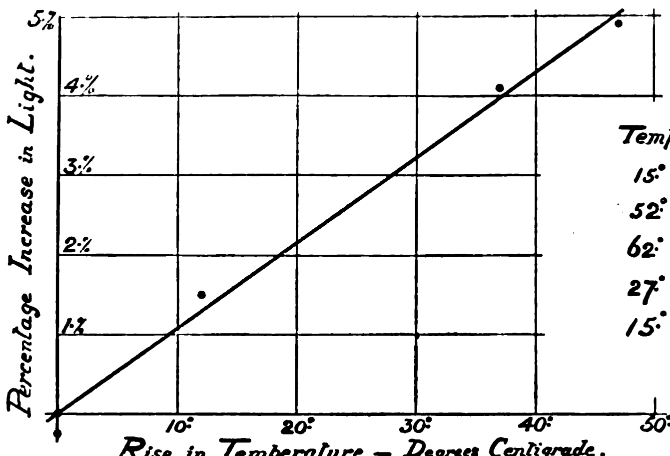
With a simpler form, however, of the Vernon-Harcourt lamp, known as the Simmance pentane standard lamp, I have worked and found it extremely useful in the laboratory. The chief advantages of this lamp are that it quickly attains its normal candle-power, and also that it has no chimney surrounding the flame. The advantage of its having no chimney is that it does not take a long time to heat up. This was a very serious objection to the Woodhouse and Rawson form of the lamp, which certainly took half an hour before the lamp gave its normal amount of light.

Turning to incandescent lamps, when an incandescent lamp is to be

Mr. Morris. used as the working standard, we must first of all discard all filaments which have more than one loop in them. The horse shoe filament is a convenient one, because it is all in the same plane, and therefore one can tell accurately the distance that the filament is from the photometer with which one is working. I have had the pleasure of working for Dr. Fleming with some of these Fleming-Ediswan standard lamps some six years ago, and comparing the work that one can do with the ordinary horseshoe filament in the small and large bulbs, I consider that the large bulb form is much more satisfactory. Any slight change in the orientation of the bulb does not influence the candle power so seriously if the large bulb is used. Incandescent lamps of any kind have the advantage over flame standards that they are entirely unaffected by variations in carbonic acid, moisture, and barometric pressure; but, on the other hand, great care has to be taken in the measurement of the electric pressure. Mr. Edgcumbe has remarked that if your voltmeter gives you a result accurate to within half per cent. or 1 per cent. you get quite near enough results. That may be so in ordinary lamp photometry for works measurement, but if you want to obtain a degree of accuracy of 1 per cent. in the light, it is essential that the pressure be measured to one-sixth part of one per cent. [Mr. Edgcumbe: I meant when the two lamps are in parallel; not when you are working against a primary standard.] Perhaps I have misunderstood you. However that may be, in any case where a single lamp is used for photometry, if you require an accuracy of half a per cent. in your candle power, you must measure your volts to $\frac{1}{12}$ or $\frac{1}{13}$ of 1 per cent. Measuring instruments are then practically out of the question, and a potentiometer, in some form or other, almost becomes a necessity. The filament that Dr. Fleming has shown is one of the horseshoe type. It might be a little more satisfactory if that filament could be held in a rigid position, and so be maintained in a perfect plane, if possible, because there is a tendency for it to wobble slightly under certain circumstances. But these are only minor criticisms, for I consider the large bulb lamp is certainly a very marked advance.

There is just one other point, and that is the regulation of the temperature of the photometer room. I should be glad to know if Dr. Fleming has carried out any experiments with regard to the relation of temperature and the candle-power of these lamps. Since the last meeting it occurred to me that I might put the matter roughly to the test, and I carried out the following experiment: I had two 55-volt 16 candle-power lamps connected in parallel so that they were run at exactly the same voltage. They had horseshoe filaments and were fixed six feet apart. A photometer was placed between and their candle-power was carefully compared. Then an arc lamp resistance which had been placed underneath one of the lamps was arranged so that it could be heated by means of an electric current and so the temperature of the space round one of the lamps could be varied, and in the curve the results are indicated. Along the base-line is plotted the rise in temperature of the space surrounding the heated incandescent lamp. That temperature was measured when the lamp was turned out. The

candle-power is measured upwards, but in this diagram I have plotted the percentage increase of the light, not the absolute candle-power; so if one considers it as a matter of total candle-power, the base-line is one hundred times the width of one of these divisions down below. So we have percentage increase in light and rise in temperature. There were only four points obtained, after which the lamp was allowed to cool. The spot below the starting point of the curve indicates the nearness with which one can get back to the original value. The table accompanying the curve shows the relation of the actual temperature of the space surrounding the lamp when it is switched out, to its candle-power. Mr. Morris.



Temp.	C.P.
15°	16·00
52°	16·65
62°	16·78
27°	16·24
15°	15·96

FIG. H.

This experiment shows that in these particular 55-volt lamps for every 9° centigrade rise in temperature the light given out by the lamp rose 1 per cent.; so quite apart from the necessity of ventilating the photometer-room and keeping it cool for potentiometer work and flame work, it is also advisable to keep the temperature moderately constant so that the light given out by one of these working standards shall remain constant.

Mr. F. H. VARLEY: There are one or two points to which I should like to draw attention. The first is connected with the pentane lamp, to which Mr. Vernon Harcourt referred on the last occasion. Dr. Fleming gives two readings taken six years apart, in which a variation in the glow-lamp of about $\frac{1}{12}$ occurred in the six years; this he attributes to the fact that the pentane lamp was not reading at its full value, and hence the higher reading for the incandescent lamp. Referring to the air-gas pentane lamp, such a variation there is no doubt is not due to any fault of the pentane, nor to the lamp, but is entirely due to impurities in the air. The lamp draws in air through the valve, and is actuated by pentane vapour. If the air is moist, then Mr. Varley

Mr. Varley. there is a repellant action, and it does not absorb so much pentane vapour as when the air is perfectly dry. We know the effect of moisture in the air as far as combustion is concerned: it cools the flame, and causes imperfect combustion of the carbon, and the flame

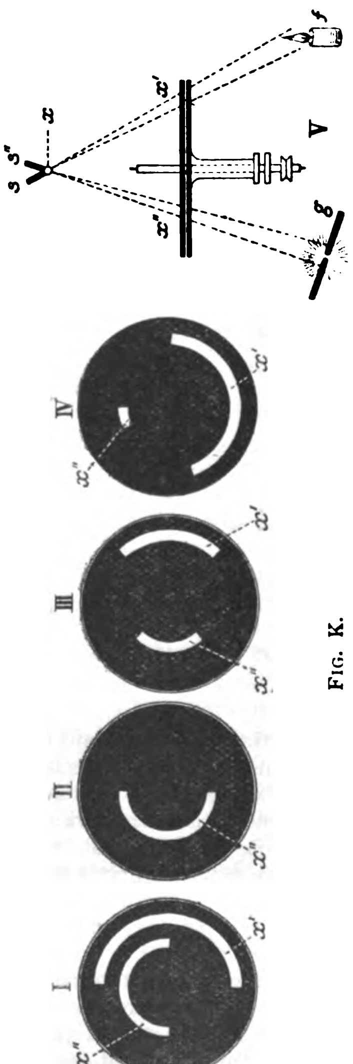


FIG. K.

I. The disks of the photometer showing the semicircular windows and their relative position on the disk. The second disk has precisely similar windows, but the window x' is reversed, being on the left.

II. Represents x'' fully open, x' being shut.

III. Shows the position of x' and x'' when two equal lights are being measured.

IV. The relative opening of the windows x' and x'' when a powerful light is being measured against the standard, say, electric arc light and a 10-candle lamp standard.

V. Bird's-eye view showing the equal distance of the shadow-receiving screen from arc light and standard candle; also, in section (indicated by parallel thick lines) the front disk, the back disk, a central axis attached to the former, a hollow axis attached to the back disk, f standard light, g light to be measured, x shadow-casting pin, ss' the shadows. Between f and g a suitable screen is provided, not shown in drawing, to prevent one light interfering with the other.

smokes. If precautions are taken to render the air perfectly dry, and the organic matters, chiefly ammonia and carbon dioxide, be removed, then having got a standardised pentane, a standardised burner, and a standardised atmosphere, not only to make the air-gas, but also to burn

it, one should have removed all the variations due to the pentane lamp, except those of barometric pressure and temperature. Those surely can be calibrated, and a constant given for each millimetre change of pressure, or each degree of temperature. To obtain standardised air, it should be drawn from an independent source free from the contaminated atmosphere of the photometer-room, passed over lumps of pumice-stone saturated with potassium permanganate solution to remove organic impurities, then through unslaked lime, and finally through calcium chloride to extract moisture and CO_2. Mr. Varley.

With regard to the question of photometry, in the year 1889 I devised a photometer which is a direct-reading photometer (Fig. K) and which has the advantage that it can be used in a very small space. I made these two cardboard disks to illustrate the principle of it. It is a sector photometer. There are two openings, one is now small and the other large. If I turn one disc upon the other so as to get a full opening of one sector I shall entirely close the other. When it is rotated you have two rings of light. If we twist the disks we shorten the length of one ring, and make a corresponding opening on the other. We have two lights passing through, one through the small opening and the other through the large. The large is the standard candle, and the small one the arc light. These can be thrown at a distance of a metre from the screen; both lights are at the same distance, and therefore the angular value is the same; it gives a direct measure of the intensity of the two lights. Then comes the question of the hetero-chromatic trouble. In this disk when it is fully opened there is 50 per cent. of obscuration. This light shows a penumbra, and the penumbra increases in proportion to the luminosity. If we take an arc light—that is, 2,000 candles—then a slit would be opened $\frac{1}{1000}$, and this slit would represent 1,999 divisions. Therefore we get on the scale this indication. The divisions are numbered, and read from right to left and left to right. We then have the index pointing to 1,999 on the one reading, and one division on the other. It is a direct-reading photometer, and can be used in a very small space. As to the hetero-chromatic effect, having a minimum of 50 per cent. penumbra, any slight variation in colour, pink or green light, for instance, that slight amount of tint which is very sensitive to the eye and so fallacious when seen on a Bunsen screen, is entirely obliterated by the penumbra obscuration of the disk. I can compare it in this way. Supposing we take two tumblers of water, one with a little green paint in it and the other a little pink paint. The contrast between those two is very great. Put a little Indian ink into both the tumblers and you cannot tell which is the pink tumbler and which is the green tumbler. So this penumbra of the disk gets over the difficulty of the hetero-chromatic effect.

Mr. L. GASTER: I think that Professor Fleming is to be congratulated on bringing such a valuable paper before us. Regarding the 10-candle-power pentane standard, I should be very much obliged if Mr. Vernon Harcourt would give us some information as to the price of pentane and the price of the lamp, because that might have an influence upon some of the people who wish to use the lamp for their photometric work. The amyl-acetate lamp is very cheap whereas this one Mr. Gaster.

Mr. Gaster. is rather more expensive. From what I have been given to understand, when once the lamp is adjusted it works very well, but I should like to know whether there are any difficulties in manufacturing the lamps so as to make them to agree sufficiently with one another to serve as reliable standards. In order to avoid any doubts on the accuracy of each standard I would venture to suggest that every lamp sold should be first tested at the National Physical Laboratory, and each lamp should be accompanied with a certificate of approval, after having been compared with a recognised standard of light.

Professor Fleming deserves our thanks for his important researches on the use of the incandescent lamp as a standard. This form of standard promises to be largely used because it is much easier to keep the lamp under the prescribed conditions so as to yield the standard unit of light, if the lamp has once been tested against an admitted standard.

Professor Fleming has suggested that every lampmaker should supply with his manufactured lamps the polar curve of their luminous intensity; but I must point out that not all manufacturers supply also the carbons for their lamps, and as improvements are constantly being made in the manufacture of carbons, several patents have only recently been taken out in this direction. I think that it will be necessary first to settle upon a standard carbon with which the tests shall be carried out, giving the dimensions of the carbons and the current and voltages used, as all these conditions contribute to affect the results obtained.

Regarding the question of photometers, I see that Professor Fleming mentions also Blondel's photometer, and Mr. Blondel's work in this direction is well appreciated, but I wish to add that if the Professor would have continued his valuable researches a little further than 1896 he would have come upon a very interesting improvement on Blondel's photometer, described by Prof. C. P. Matthews at the meeting of the American Institute of Electrical Engineers on September 27, 1901. [See *Science Abstracts*, No. 623 of 1902, and 1478 of 1902.] With the aid of this photometer you can practically get in one reading an illumination upon the photometer screen proportional to the mean spherical intensity of the source, which may be an open or enclosed arc lamp, simplifying the process of photometry very considerably.

With regard to the units suggested by the author I quite agree with nearly all the remarks he has made. In using as basis 10 and the metre, he brings us nearer to the Continental countries, and I hope before long that the metric system will be used extensively also in this country. Considering the difficulties to which the Professor alluded in the selection of an international standard of light, it is a great pity that the question of nationality should be involved; if science is to be worthy of the name it should not recognise any such boundaries, and if a good standard has been worked out in one country and is the best existing, it ought to be adopted all over the world and no national feelings should interfere with its adoption. The 10-candle-power pentane lamp of Mr. Harcourt, the incandescent lamp described by the Professor, and the achievements with the platinum standard ought to

be carefully studied by those interested in the matter so that at the next International Congress of Electrical Engineers there should be ample material brought before the meeting so as to come to a better understanding regarding the adoption of one international standard of light, to the benefit of all parties concerned—professors, manufacturers, and consumers. From my personal experience in testing incandescent lamps, I can corroborate Professor Fleming's remarks regarding the great discrepancy prevailing in marking the lamps to-day. I most heartily thank Professor Fleming for his work as one interested in photometry work generally, and particularly in the manufacture of carbons. Mr. Gaster.

Mr. H. E. MOUL: Any remarks that I may make are intended to apply only to the commercial and not the scientific side of incandescent lamp photometry. I am not open to make any predictions with regard to the scientific side, but it seems to me that as engineers we have a great interest in it, and I think, here at all events in England, we do very little with it. Dr. Fleming opens his paper by pointing out the differences in tests by different observers, at different times, and I suggest that a standard for instruments is almost as essential as a standard of light. Practically it comes to this: no photometric results are really comparable when taken by different observers with different instruments. These accuracies of ½ per cent. and 1 per cent. do not then occur in practice. It seems to me that if comparative tests are to be made at different places, one in Germany and one in England and so on, one must adopt a standard class of photometer for this purpose, just as much as a standard source of light. Experience shows that it is only by using similar instruments that different tests have been made to come within ½ per cent. of each other. As regards the actual photometer head, any one who has worked with a Lummer-Brodhun will never go back to the old grease-spot photometer, but the Lummer-Brodhun instrument is now being superseded by the Krüss type with straight telescope and contrast field. As engineers, we are not interested so much in what is to be the actual light standard as in getting a standard at all; we cannot in actual commercial work refer any readings we take to a standard over here. There is none, and the net result of this is that lamp-makers supply what they think is a good thing, and the central-station engineers say it is a bad thing, and really neither party knows what they are talking about. If they think they know it they have no standard for reference and no place from which to obtain any legal decision on the question. While this battle of the standards is going on we ought to have one class of standard to which readings can be correlated, even if something else should be adopted afterwards. Unless every central-station engineer is going to set up his own standard, he wants some calibrated instrument other than what we have seen here; standardised lamps are the right thing for this purpose. On the Continent you can get them in big bulbs and certified by the Reichsanstalt at a cost of half-a-crown each, with the position marked in which they have been standardised, and you know that they are sufficiently accurate for commercial purposes. Mr. Moul.

The use of potentiometers is very pretty in theory in the laboratory,

Mr. Moul. but how they will turn out in the ordinary course of everyday work I do not know. When stations supply lamps, which will in the future be the case, and 5,000 lamps are daily put through the photometer-room, what will be the state of the potentiometer then? In practical work, to put that quantity through a photometer-room, D'Arsonval reflecting galvanometers answer every requirement.

Dr. Fleming has shown a diagram of this balancing means of photometry. It is not cited in the references, but practically that is the Strecker type of photometer which was illustrated and described in Germany in 1888 (*Strecker Hülfsbuch*, 1888, p. 267), and is now adopted by the German Institution of Electrical Engineers, only in this case the mirrors have been left out. Behind the lamp under test there are two mirrors, five inches square, at an angle of 120°, and the apex of these is placed at the zero of the bar.

Dr. Fleming has made one statement with regard to lamp manufacture which I venture to contradict. He says that lamps blacken less the worse the vacuum. That may be, but it does not mean that if you get a lamp that does not blacken, the vacuum is bad. Possibly this was the case with the antiquated methods of pumping which are gradually being eliminated here, but in standard practice it does not apply. I have laid on the table the report and the lamps of a life-test at 2·5 watts per candle (Harcourt Pentane Unit) by the Reichsanstalt in Berlin in which blackening was not noticeable in the lamps tested. I have done this to show also the conveniences that a manufacturer has over there in regard to this class of work. There are seven lamps on the table which have been tested at the Reichsanstalt, and each lamp is marked with the Government mark, and there is the legal certificate in connection with it. If there is any dispute here, one side calls in an expert, and the other side, if it can afford it, calls in three, and they each fight it out, and we are none the better for it, but are left with a big bill to pay. We have a Reichsanstalt here, and we are still a long way off a standard; in the meantime we are being used as a dumping-ground for every bad lamp manufactured abroad simply because the foreigner knows that we have not a standard, whereas they have, and so cannot sell such lamps at home. It is time we did have a standard; the Reichsanstalt here ought to give us just as much as we can get over there; we want a standard and lamps calibrated in terms of the standard selected. If we could get these lamps they would give us a means of checking our supplies, and if then there is dispute between maker and customer, we have our Reichsanstalt to refer to; equally it ought to be possible for our Anstalt to authorise some of our other laboratories such as Owens College, University College, and others to undertake work of this description and give certificates equally valid with those of the Physical Laboratory. This power to test to Imperial standards and issue legal certificates concerning the tests has been delegated with the happiest results to several of the leading University laboratories in Germany by their Reichsanstalt.

Prof. Ayrton. Prof. W. E. AYRTON: We must congratulate Dr. Fleming on having given us a most interesting paper on a most interesting subject. He

Prof. Ayrton.

commences by pointing out what is most true—what the President pointed out in his inaugural address—viz., that while central station engineers devote a great deal of attention to the efficiency of their boilers, engines, and dynamos, and are aghast at an extra loss of 1 per cent. in the generating plant, they seem to be, if I may say so, a little oblivious of the fact that in this city, at any rate at the present time, the main use of the electric current is to supply light, and therefore the glow-lamp is just as important as the boiler, or the dynamo or the steam engine. American electric light companies so thoroughly appreciate this that they, as you probably all know, insist on supplying lamps, and would almost prefer to *give* lamps than to leave the consumer to buy inferior ones. If you want to see what has been done in America in the testing of lamps, I would refer you to an almost extraordinary report of tests that has been carried out by the Standard Oil Company of America, who wanted to find out, not only in a technical way, in a scientific way, but a commercial way—which is scientific, of course—what qualities of lamps could be obtained in the United States. I will not go into the report which has been issued by the General Electric Company of America under the title "Agents' Handbook of Lamp Tests," but I may tell you that it was most interesting to me, and I am sure it will be to you when you read it, to find that a commercial company like the Standard Oil Company had carried out such an excellent piece of work.

Dr. Fleming draws attention to the vagueness in the testing of lamps. I have referred to that on previous occasions in public, and when I have done so it has, I fear, been considered that I was exaggerating. He speaks about a difference of 25 per cent. I will give you an instance, because it happens to deal specially with photometry, that occurred about a year ago, where the difference in the results of the light tests was more like 33 per cent.

A certain firm in this country which makes lamps sent me some 16-candle power lamps to test. These were not lamps bought in the open market; they were not lamps chosen by me at random from the maker's stock, but they were presumably selected lamps, because they were sent to me by the makers. My report of such lamps, no doubt, might have been too favourable to the makers, but you could hardly have expected the reverse. Yet when I tested the lamps I found that instead of getting 16 candles—they were life tests, of course—the life curve of some of these lamps never showed more than 10·8 candles during the 600 hours' run; the average candle-power was 7·85, with average inefficiency of 5·6 watts per candle. That was the class of lamp sent me a year ago by the makers themselves. Now this is what they wrote me when I sent them the report: "We express our disappointment at the results. The curious facts about these tests is, that two other tests were made at the same time upon the same batch of lamps, independent of your own tests here on the two mentioned, and each gives the candle-power of the lamps at 16 candles." So that, as there were three tests against me, it seemed rather a staggerer. Of course I examined the measuring instruments most carefully—the ammeter, the voltmeter, and particularly, of course, the standard of

Prof. Ayrton.

light. I was using then, and still use, among other standards, the Dibdin 10-candle standard—a standard not referred to by Dr. Fleming in his paper, but which was reported on so highly by the Committee of the Board of Trade in 1895. That Committee went so far as to say: "We therefore recommend that a pentane-air flame, furnished with a Dibdin-argand burner, having the form and dimensions set forth in the Appendix (Section IX.) and used in the manner there defined, be accepted as giving the light of 10 standard candles, and that this flame be authorised and prescribed for official use in testing the illuminating power of the gas supplied by the London Gas Companies." That was the recommendation in 1895, and I used such a standard. Mr. Dibdin was kind enough to test my specimen of this standard against the actual specimen which had been examined by the Board of Trade Committee, and still we could find no error in our tests of the glow-lamps. I therefore reported to this particular company that what I sent was my final result, and that in spite of the three independent tests giving results differing from my own, the lamps did not give 16 candles, but some of them never gave more than 10·8 candles at the specified pressure at any period of the test. I then asked them would they give me the names of the persons, whom they thought most trustworthy, who had tested the lamps, and I would endeavour to run the matter home and find out the real cause of the discrepancy. They did so, and I found certain errors in the ammeters and voltmeters. I will not go into that question now, because it is purely an electrical question, although it was necessarily concerned with the photometry of the lamps. I will deal now with the photometric part alone, especially as it concerns a point not referred to by Dr. Fleming.

The standard of light employed by these persons was the Harcourt pentane lamp, but not, however, the more recent pentane standard. The present forms of the 1-candle and of the 10-candle standards have no wick, but in the old days the 1-candle standard Harcourt pentane lamp had a wick, and I found that a great deal depended on the way in which the wick was treated. Messrs. Woodhouse & Rawson, the makers, when they sent out this pentane lamp in 1890, issued certain printed directions regarding the mode of using the Harcourt pentane lamp, but the directions were not sufficient, because I found that by not paying proper attention to certain precautions not clearly mentioned in these directions you could get a difference in the light given by the lamp. The difference between my estimation of the light given by the glow-lamps and the result given by the other experimenters was about 33 per cent., *i.e.*, 10·8 candles as compared with 16 candles, which is about 33 per cent., and I found that a portion of this difference was due to the light given out by the Harcourt pentane standard lamp as used by the firm of testers in question being less than the light given out by the similar Harcourt pentane standard lamp in my laboratory. In the instructions one is told to light the lamp by inserting a piece of cotton-wool dipped into spirits between the outer cylinder and the burner. The piece of cotton-wool cannot easily be inserted from below even if one were told to do so, but as one is not, one naturally tries to light the

lamp by inserting it from above, which it is easy to do. But the lamp will not light this way for some time, so that any ordinary person who has perhaps used paraffin oil lamps all his life naturally turns up the wick; still the lamp does not light, so he turns the wick up more until the wick protrudes from the burner, until perhaps the wick is turned up so much that the top becomes visible when the lamp is looked at horizontally. But that is all wrong, if the poor user only knew it, for then the top of the wick is liable to char. Prof. Ayrton.

Now what the user ought to be told is this: First insert the piece of lighted cotton-wool between the outer tube and the burner FROM BELOW; do *not* turn up the wick even if the lamp does not light, but leave the wick exactly as it was when the lamp was last used, and *always* not only start the ignition but cause the flame to mount until its tip is visible in the slot by simply warming the outer tube with a spirit lamp. Prof. Vernon Harcourt has been so kind as to give my assistants and myself a personal demonstration in my laboratory of how to use this pentane lamp, but for the benefit of those who have not had this advantage I mention all this to avoid their making the mistakes into which this firm of testers unintentionally fell when they brought out that the light of the glow-lamps were 16-candle ones, while we proved that some of them never gave more than 10·8 candles at any time at the specified voltage.

But there are other sources of error in the instructions issued with these wick pentane standard lamps, for one is told therein that the flame should be adjusted so that the tip is visible between the upper and lower edges of the slot; whereas, as far back as 1895, my students pointed out to me as the result of their tests that the Harcourt pentane standard lamp gave nearly 4 per cent. more light when the wick was turned up so that the tip of the flame was at the middle of the slot than it did when the tip of the flame appeared just above the bottom of the slot.

Lastly, there are differences between the amount of light emitted by different specimens of these lamps even although the lamps generally appear to be of the same form, and pentane, obtained from Messrs. Miller, of Oxford, is taken from the same can to fill the glass reservoirs of the two lamps up to the same level. Mr. Robertson, of glow-lamp reputation, has kindly lent me his specimen of the Harcourt pentane standard lamp, and many comparisons have been made between his lamp and our own by Messrs. McEwen and Dow, two of the assistants at the Central Technical College, with the following results—the lamps being called respectively the "Robertson" and the "C.T.C.," although, of course, neither Mr. Robertson nor the Central Technical College are responsible for the construction of these two lamps. It should be mentioned for those who are not familiar with this type of lamp, that two cylindrical metal blocks are supplied, with each lamp, marked respectively 1 and 1·5, and it is supposed that when the aperture for the emission of the light is carefully adjusted with one or other of these blocks or distance pieces, and the wick lighted in the proper way and the other precautions adopted, that the lamp becomes a one or a one-and-a-half candle standard respectively.

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Well, these were the results experimentally obtained :—

I. $\frac{\text{Robertson 1 candle}}{\text{C.T.C. 1 candle}} = 1{\cdot}05$ even when the *same* block (viz., the *Robertson* 1) is used to adjust *both* lamps and the flame is adjusted to the *centre* of the slot in each case.

II. $\frac{\text{Robertson } 1\frac{1}{2} \text{ candle}}{\text{Robertson 1 candle}} = 1{\cdot}40$ when the *Robertson* 1½ and 1 blocks are successively used in the *Robertson lamp itself* and the candle-power compared with another standard of fixed, but not necessarily known, value. Flame in Robertson lamp kept adjusted to *centre* in *both* comparisons.

III. $\frac{\text{C.T.C. } 1\frac{1}{2} \text{ candle}}{\text{C.T.C. 1 candle}} = 1{\cdot}45$ when the *Robertson* 1½ and 1 blocks are successively used in the C.T.C. *lamp itself* and the candle-power compared with another standard of light of fixed, but not necessarily known, value. Flame in C.T.C. lamp kept adjusted to centre in *both* comparisons.

IV. $\frac{\text{C.T.C. } 1\frac{1}{2} \text{ candle}}{\text{C.T.C. 1 candle}} = 1{\cdot}51$ when the above experiment, No. III., is carried out with the *C.T.C. lamp*, but when the *C.T.C.* 1½ and 1 blocks are used instead of the two *Robertson* blocks, etc.

V. $\frac{\text{Robertson 1 candle, Robertson block used}}{\text{Robertson 1 candle, C.T.C. block used}} = 1{\cdot}035$

Hence, combining the above results, it follows that if you test the light of, say, a glow-lamp, using the Robertson pentane lamp with the Robertson 1 candle-power block, and with the tip of the flame at the centre of the slot, next test the same light with the C.T.C. pentane lamp, using the C.T.C. 1 candle-power block but with the tip of the flame at the bottom of the slot, you will obtain about $5 + 3{\cdot}5 + 4$, or about 12·5 per cent. difference in the estimation of the light of the glow-lamp.

Some tests subsequently made through the kindness of Prof. Vernon Harcourt and under his superintendence, at the testing-room of the Gas Referees in Victoria Street, show that if these two lamps respectively be used, each with its own 1 candle-power block, as supplied by the makers, and the tips of the flames be adjusted as described above, the estimation of the light of a glow-lamp, say, will differ by the amount already mentioned, that is about 12·5 per cent., although the second set of tests divides this error somewhat differently among the different causes.

In Professor Vernon Harcourt's patent specification No. 11,985, of 1887, the dimensions of each of seventeen parts of this type of lamp are

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given. On having measurements made of these parts in three specimens of this lamp, which are at present in my laboratory, I find that all three lamps differ from one another, and that no one of the three has exactly the dimensions given in the patent specification.

Of course these variations are due *not* to faulty design on the part of the inventor, but to errors in mechanical construction of these pentane standard lamps and to imperfections in the printed instructions for using them which have been sent out by the makers.

Further there is one other difficulty we always have to deal with, which has been raised by the last speaker. What do we mean by a candle? Some people insist on saying that they mean by a candle a candle which is made in Germany, as most things are now made in Germany. Dr. Fleming shows you what great differences have been found in the comparisons between the amyl acetate standards and the British standards, and he puts down those differences to the method of testing. I go further than that. I venture to think that the amyl acetate standards that have come over to this country, and which have come into the laboratories, differ a good deal one from the other. So it is not merely a difference in the method of testing, but the candle made in Germany is not always the same candle. Mr. Moul said that anybody who had used the Lummer-Brodhun photometer would never go back to anything else. I was talking about that only this week to the authority on photometry who spoke on the previous occasion, Sir William Abney. He said his opinion was quite the contrary. He frequently has men come into his laboratory to work who come with a predilection in favour of the Lummer-Brodhun photometer, but they almost invariably before they leave him go back to the old Rumford photometer. What is the enormous value of the Rumford photometer? It is that it is not made erroneous by stray light. A great many errors are introduced into photometric work by stray light, and all photometers which have light coming in on both sides are susceptible to this error. Sir William Abney says that he considers the Rumford photometer far superior to the Lummer-Brodhun, or any photometer in which the light comes in on the two sides. I have had brought here for a variety of reasons a photometer which a colleague and myself made nearly twenty-one years ago. We were put in a great difficulty at the Paris Exhibition of 1881. We had to report on the different types of lamps in the Exhibition. The report was published in *The Engineer* newspaper afterwards. We had to devise a portable photometer for the purpose, because the lamps were in all parts of the exhibition. *This* photometer was, therefore, devised and called the "Dispersion Photometer."

(The photometer was exhibited.)

It has one thing which I may draw attention to, because from what Dr. Fleming has said the importance of it does not seem to be appreciated even now, namely the 45° mirror. He pointed out that people still—and it shows how beautifully conservative our country is—make photometers with a mirror turning about an axis in the plane of the mirror like an ordinary toilet-table looking-glass. The consequence is,

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that the amount of light absorbed varies with the way in which the light falls, and is reflected. Instead of turning your mirror in that fashion you ought to turn it about an axis making an angle of 45° with its plane, for then the light always falls at the same angle on the mirror, and always leaves at the same angle, and the proportion absorbed is constant. The use of this 45° mirror Dr. Fleming draws attention to in connection with his arc-lamp arrangement, on page 146 of his paper. I can testify that that arrangement is an extremely good one for getting the polar curve of the arc-lamp. The method, as he has already explained, is to compare the light given off by the arc in any direction with the light given off horizontally by the same source. I happen to know a good deal about the apparatus, because it was devised and constructed by an assistant I had several years ago, a Mr. Carter, who, like many other of my men, has been absorbed by the General Electric Company of America. Mr. Carter later on published a series of articles in the *Electrical Review* on Photometry, and in the article of August 3, 1900, he gives a complete account of the way of using this 45° mirror to accomplish the result that Dr. Fleming has achieved on p. 146 of his paper. He has, in fact, practically arrived at the same arrangement, so that you can compare the light going out from the arc at any angle with the light sent out at a particular moment horizontally. Mr. Carter's work is also the more interesting because in this series of articles—there are five or six of them published in the *Electrical Review* in the middle of 1900—he used the "distinctiveness" photometer, I think he called it. *This* is one of the paraffin blocks he employed. I daresay you all know the Joly paraffin block photometer, where you have two blocks of paraffin wax separated by tinfoil. There is nothing new in that, but what was new in this photometer was the ruling of the photometer screen used by Mr. Carter, the arrangement of lines getting finer and finer, only in this case he used radial lines. But Mr. Carter, in spite of his doing most excellent work on photometry at the Central Technical College, as published in the *Electrical Review*, I think made the same mistake that Dr. Fleming has made. In using the "distinctiveness of vision photometer," you are not measuring the brightness of light at all. Sir William Abney said a word or two about this on the last occasion, and I want to emphasise the criticism Sir William offered. There are many things that are interesting in connection with two lights—how much it cost to produce them, what you pay to buy the lamps, what is their relative weight, etc.—but there is one thing which is particularly interesting, their relative brightness, and that is what the photometer has to measure. I do not think that what have been called distinctness of vision photometers are photometers at all, and I do not think they have anything to do with photometry. A photometer is used for the purpose of comparing the brightness of two lights, and not for finding out how easily you can see something or other in either of the lights, for that depends on something totally different from the brightness of the lights. Therefore I think that Mr. Carter, when he devised that arrangement described here, fell into the same mistake that Dr. Fleming has fallen into.

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Dr. Fleming takes the view that you cannot compare two different coloured lights. There again, if he will allow me to say so, I think he has fallen into a very big error. He laughs at the idea of using coloured glass. You remember he made some humorous remarks to you on the last occasion, and obtained the laugh of the audience, but that little joke was directed at me, and as he has thrown down the gauntlet I am quite willing to take it up. In this photometer which Prof. Perry and I used at the Paris Electrical Exhibition of 1881, we had attached to it a frame containing red and green glass. Dr. Fleming says that the old method of looking at the photometer screen through red and green glass is quite unscientific. How is it unscientific? He would not say, I suppose, that spectro-photometry was unscientific. Spectro-photometry has a long name attached to it, and as I know to my cost, you have to buy a rather expensive instrument if you want to do it well. But what does spectro-photometry do? It simply takes a bit of the spectra given by two different lights, and compares the brightness of those two portions of the two spectra. What does this frame with the red and green glass in it do but that? Suppose you take a piece of what is technically called ruby-red glass and a piece of signal green glass, and supposing you take the precaution, as we used to, of selecting our red and green glass, so that on putting them one over the other you almost have blackness when a bright light is looked at, then you first make your photometer balance with the red glass and then with the green glass, are you not really performing spectro-photometry? So far from thinking it unscientific, I think it is most useful. But you may say, "How can two lights have a totally different ratio, being, say, 3 to 1 and also 2 to 1?" Quite easily —why not? If you want to look at the red roses, then the arc bears to the candle a certain proportion: if you want to look at the green leaves attached to the red roses, then it bears a certain totally different proportion, and that is what you mean. In looking at the red flowers the arc is so many times as good as the candle: in looking at the green leaves the goodness is something totally different. I go a step further. Dr. Fleming referred us last time in his interesting and most instructive paper—I must congratulate him on the way in which he delivered it, I envy his power of putting it before you—he referred to Purkinje's experiment. He had a Ritchie wedge, illuminated by a glow-lamp behind a piece of red glass, and another glow-lamp with a piece of green glass before it, and he told you, and possibly showed you after the reading of his paper, that if you put the wedge so that the two lights balanced, that is the brightness appeared to be the same, and then if you doubled the distance of each lamp from the wedge, you would no longer get the balance. It is simply an optical delusion with weak lights, and the phenomenon does not exist at all with ordinary lights. If it were true it would mean that colour photography was a snare. Is it or is it not a fact that if by proper means you balance a red light against a green light, and then double the distance of each light from the photometric screen, you will get a balance the second time? I can assure you you can. There are two ways in which you can compare them. You can compare the red and

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the green light looking through green glass: and then if you alter the distance you will find the inverse square law holds. If you compare them with the red glass, you will find again that the inverse square holds. That is, if one is three times the other at one distance, it will be three times the other at any other distance. Let me go further; leave the glass on one side. It is quite possible to compare a red light with a blue light without using any coloured glass at all, and to get marvellous accuracy. The secret was given by Sir William Abney, but it is so absurdly simple that I want again to impress it upon you, because the result is wonderful. Mr. Medley, in a paper which he read, with myself, before the Physical Society in 1895, described how, by taking two different coloured lights, you could get the same measurements over and over again, within $\frac{1}{3}$ per cent., without any coloured glass at all. The secret is this. First, you oscillate the photometer until you get the best balance you can, then you oscillate one of the standards, one person oscillating it while the second person is getting a final adjustment of the photometer. I will give you the actual results we have obtained, and they will show you the sort of accuracy with which it can be done. We compared a green light with a yellow light. The yellow light was a 100-volt glow-lamp underrun at 83 volts: the green light a 100-volt glow-lamp overrun at 107 volts, green gelatine being in front of the latter. They were first put at 140 centimetres distance, and the measured ratio of the one to the other, when properly tested, was 1·51. They were then put at double the distance, 280 centimetres, and the measured ratio of the one to the other was 1·52, almost exactly the same, in spite of Purkinje's experiment. Next we compared the underrun lamp with the overrun lamp when red instead of green gelatine was put in front of the latter, that is we compared a dullish yellow with a bright red light, and the result obtained at the 140 centimetres distance between the lamps agreed even still more closely than before with that obtained when they were separated by the 280 centimetres.

Hence it is certain that whatever may be found with very *dull* lights—if two totally differently coloured glow-lamps, even when one is underrun and the other overrun, are *properly* compared, the same result will be obtained whether they are at 140 centimetres distance or at 280 centimetres.

Mr. Patchell.

Mr. W. H. PATCHELL: I was brought into this matter as when considering raising our pressure to 200 volts, I was constantly met with the assertion that the 200-volt lamp was not so good as the 100. I looked up the authorities, particularly those mentioned at the Board of Trade inquiry about a couple of years ago, and I found, like the two Professors on either side of me, that they practically cancelled out,—you could believe whichever you liked. I therefore thought the only thing to do was to go into the subject myself, and looked round for a photometer. I only wish I had had Dr. Fleming's paper by me at the time, because it would have saved me much trouble, and I feel we are greatly indebted to him for the concise way in which he has placed the subject before us. Mr. Edgcumbe said the paper was a little disheartening. So it is. But a great many other things are. I constantly get circulars saying that if I

use somebody's engine I can save 25 per cent. of my steam: by using sombody else's oil another 10 per cent., by using somebody else's waste and somebody else's packings I can save 30 per cent., so that if I used everything as per advertisement I might be actually selling coal instead of buying it! Still we do not get disheartened. I feel we must be thankful for what we can get, and go on with the photometers that the Professors have provided us with. After looking round I settled on the photometer which Dr. Fleming mentions on p. 123 of his paper, made by Wright of Westminster, with the double candle standard. It is the Pentane standard, which I certainly prefer to the Hefner standard, but I had leanings towards the other disk, the Lummer-Brodhun. When I found I could not get a sort of cross-bred photometer, I took Wright's as I found it, with the exception that I insisted on having a scale calibrated in candle-power, and you would be surprised at the powers of persuasion that were necessary to get that carried through. At last we succeeded, and then we began our measurements. We were not in the happy position apparently, by the results given, that Dr. Fleming is in, nor did I say that I wanted lamps for testing, and as I was not a Professor they were not picked and sent to me. I had them sent in batches of half a dozen, 8 and 16 c.p.; 100 and 200 volts. On p. 163 Dr. Fleming refers to 8-candle lamps which were as a matter of fact nearer to 10-candle at 30 watts. I wish I could get them, because they were absent from the samples I had sent in. We found that in samples tested by us the 16-candle 100-volt lamp had an average candle-power of 12·76, and an average inefficiency of 4·8 watts, while for 200 volts the candle-power was 12·80 and the watts 4·72. The 8-candle 100-volt had an average candle-power of 7·76, and an efficiency of 4·24 watts, while the 200-volt lamps gave 8 c.p. for an average 4·20 watts. Therefore we did not get the 30-watt lamp at 10 candles. If the reading of this paper will stimulate the lamp manufacturers to send us better lamps, we shall be thankful to them. Mr. Patchell.

Mr. ALBERT CAMPBELL: The amyl-acetate lamp has been rather disparaged by Dr. Fleming, but I think it is not so bad as he makes it. For example, the colour of its light does not compare very unfavourably with that of a glow-lamp that has run more than half its normal life, and it is important to test glow-lamps in such condition. The work done by the German Reichsanstalt, using the Hefner lamp as standard, seems to me to afford the best proof of its practicability. I have compared, with the greatest care, glow-lamps tested seven or eight years ago at the Reichsanstalt with others tested there quite recently, and in all cases I have found very exact agreement between the actual relative brightness and the numbers given in the certificates, the agreement being well within 1 per cent. This seems fairly conclusive evidence that the amyl-acetate lamp can be worked as a trustworthy standard. Mr. Campbell.

In using some flame standards it is important to guard against vibration. For instance, in Simmance's wickless pentane lamp, in which the flame is not screened in any way, I have noticed that very slight vibration has a large effect on the height of the flame and upon the candle-power.

Mr. Campbell. With regard to Dr. Fleming's proposed new unit of candle-power, for two reasons I think the change undesirable. First, from the linguistic point of view it is wrong to take as the name of a new unit any common word which has already a clear and definite meaning. In the second place, a unit should be of such a size that the quantities in common use can be expressed with fair accuracy without fractions. Thus, to talk of "5, 16, or 55 candle-power" seems much more convenient than "0·5, 1·6, or 5·5 lamps." The fact that for ordinary glow-lamp testing it is best to use a *standard* of 10 or 20 candle-power is no reason for making the *unit* of similar magnitude.

Mr. Lacey. Mr. T. S. LACEY: As one who is engaged in the gas industry I should like to make a few remarks. I am familiar with the one-candle standard of Prof. Vernon Harcourt, and also the 10-candle standard. I think it is hardly correct to give Mr. Harcourt's name to standards that are not arranged and devised by him. The 1-candle standard is well known, and is very accurately described, and also the 10-candle standard, but it is quite possible that other modifications may not have the same light value. In relation to the question of flame standards, they give a light varying according to the conditions of the atmosphere, barometric pressure, and so forth, but gas engineers are not concerned with this variation, provided that the standard varies in the same proportion as the light which they have to supply and with which it is compared, but it does not; and that involves certain difficulties. Small flame units (especially those of a feeble and flickering character, like the 1-candle, and, I should imagine, the Hefner standard) will be found to be more subject to atmospheric contamination and differences of water vapour than the larger ones. The 10-candle standard is certainly less affected by carbonic acid and water vapour than are sperm candles, and the Argand burner is less affected than the Harcourt standard. Until we have some determinations of the behaviour of these standards, under different conditions of atmosphere, it would be unwise to pledge ourselves to the use of small standards. The Dibdin pentane standard is a convenient one to use, but I think attention has been drawn to the difficulty of the chimney; if you break it, you break your standard.

M. J. Violle. M. J. VIOLLE (*communicated and translated*): I desire in the first place to convey to Dr. Fleming my cordial acknowledgment of his courtesy and impartiality towards myself. Mr. Petavel's very careful study of my standard has already removed the majority of the objections to it that have been raised after superficial examination. A searching investigation of the kind that Dr. Fleming would like the National Physical Laboratory to undertake would show that, even in the direction suggested by Mr. Vernon Harcourt, there is no serious obstacle to its complete realisation. I hesitate, however, to add anything to that which Dr. Fleming has been good enough to say concerning my standard.

I will not criticise Mr. Vernon Harcourt's lamp, since I have only had an opportunity of experimenting with an imperfect specimen. His practical 10-candle standard, as I understand it from Dr. Fleming's account, appears to me, however, to be exceedingly well thought out.

In regard to flame standards, I have not only experimented with a hexane standard similar in principle to that using pentane, but I have also devoted attention to the production of an acetylene standard,[1] which, although not yet perfected as completely as I could wish, appears to possess a sufficient degree of accuracy, whilst at the same time having that degree of simplicity and convenience in use which we rightly expect to find in a practical standard. M. J. Violle.

With reference to the practical standard proposed by Dr. Fleming, I feel convinced that the incandescent lamp should be completely satisfactory when employed in the form and under the conditions prescribed by the author. The large-bulbed Fleming-Ediswan lamp will henceforth have a conspicuous place in the photometric laboratory whether of the electrical engineer or of the gas manufacturer.

Mr. J. E. PETAVEL (*communicated*): Within the limited space which can be disposed of for the purposes of discussion it is not possible to go in detail into the many interesting problems raised by Dr. Fleming's most valuable paper. A few words, however, on the general aspects of the question may be of some interest. Mr. Petavel.

Were the matter not so generally overlooked, it would be trivial to emphasize the commercial importance of the subject, but strange to say whereas the greater part of the huge capital involved in the electrical industry in this country is actually devoted to the production of light, the consumer remains content to measure the amount of energy delivered, leaving the question of the quantity of light more or less to chance. The general callousness with regard to this subject is not more favourable to the best manufacturers than to the public at large. It is a somewhat strange anomaly that the same merchant who would get into serious trouble for selling as a pound of tea a packet containing 15 ounces, may without let or hindrance import and sell as 16 candle power, lamps which will only give 13. In most cases the purchaser will make no verification whatever, or perhaps, measuring only the current consumed, will express his delight at the high efficiency of the lamps. This discrepancy, even if detected, is of too usual occurrence to call for any special notice or condemnation.

I do not wish in any way to minimise the inherent inaccuracies which are necessarily connected with photometric work, or to detract from the importance of the right understanding of the difference between "luminous" and "visual" intensity. So long, however, as differences of 25 per cent. can exist between the values as determined by two different "testing laboratories,"[2] the above questions cannot be considered of immediate practical importance.

As far as the interest of the general public is concerned, the value of the work which is now carried out under the direction of the Metropolitan Gas Referees can hardly be overestimated. Unfortunately it is, *per se*, limited in its scope, and before any real reform can be hoped for the entire question of the measurement of artificial illumination must be taken up in a similar manner. As a plea in favour of the *laisser*

[1] This research has already extended over several years (see *Comptes rendus*, 1896, vol. 122, p. 179).

[2] See Dr. Fleming's paper, page 119.

Mr. Petavel. *faire* policy, it has repeatedly been urged that exact photometric measurements are difficult or impossible, but any one conversant with the subject will readily admit that, with many of the photometers and standards at present in use, an accuracy of two per cent. is easily obtained. Higher accuracy can undoubtedly be reached, and is most desirable, but measurements even if only to two or three per cent., if generally carried out, would be a vast improvement on the present state of affairs.

Turning now from the question of the actual measurements carried out (or not carried out) in everyday work, to the question of the legal standard. It is generally admitted that the British legal standard (the sperm candle) is, of all the standards in use, the most inaccurate and unsatisfactory; and yet, strange to say, no serious effort has been made to obtain a reform. It has been urged that a change should not be made until sufficient information has been obtained to warrant a definitive choice. The plea is undoubtedly well founded, but as the preliminary work must necessarily occupy some years, it would be most regrettable if time were wasted before making a start. The final choice will rest between the Violle molten Platinum standard, the Harcourt Pentane standard, and some standard based on the spectrum analysis of the radiation itself and resembling that proposed by Lummer and Kurlbaum. The work with regard both to time and expense is beyond the scope of individual research, and could be conducted successfully only at such an institution as the National Physical Laboratory, and it is satisfactory to hear from Dr. Glazebrook that steps are being taken in this direction.

From the preliminary experiments which have been made, the Violle standard seems to promise the best results. It has been proclaimed as the absolute standard of light by every International Electrical Congress, but has never been set up in such a manner as to be of practical use. The work carried out some years ago at the Davy-Faraday Laboratory has been kindly referred to by both Dr. Fleming and Dr. Glazebrook. A few further words on the subject may, however, be of interest. The electric method of fusing the platinum was not abandoned through any inherent difficulties, but simply because the preliminary results then required could be obtained in a less expensive manner, by means of an oxyhydrogen blow-pipe. The experiments were only rendered possible thanks to the kindness and generosity of the Directors of the Davy-Faraday Laboratory, but none the less in a private institution there are certain limitations which need not affect a research which is carried out by the National Physical Laboratory.

Thus the conditions under which this preliminary work was carried out were not of the most favourable character, but nevertheless, some well-defined results were obtained. These may be summarised as follows:—

1. That an increase or decrease of the total area of the molten platinum of as much as 40 per cent. will cause less than one per cent. variation in the light, *i.e.* the light is practically independent of the shape of the platinum ingot.

Mr. Petavel.

2. An alteration of 45 per cent. in the mass of the platinum ingot will cause a variation of intensity of the light of less than one per cent., *i.e.* the light is practically independent of the quantity of metal used.

3. An alteration of 140 per cent. in the size of the aperture in the furnace cover will cause less than one per cent. variation in the light, *i.e.* the light is practically independent of the shape of the furnace.

4. The purity of the platinum is important, but the metal can be obtained commercially, quite sufficiently pure for the purpose.

5. The crucible should be of pure lime, which can, of course, be easily prepared in any quantity.

6. The hydrogen should be free from hydrocarbons. Coal gas is useless, but the hydrogen obtainable commercially was found satisfactory, the design of the blow-pipe being such that any small quantities of hydrocarbons would combine with the large excess of oxygen before reaching the metal surface.

7. The gases should be in the ratio of 4 volumes of hydrogen to 3 of oxygen, but as long as a considerable excess of oxygen is maintained the ratio may be varied within wide limits.

Personally I am not aware of any other case in which the specification of a standard can be varied within such wide limits without materially affecting the results. In the case of the Hefner lamp, for instance, one per cent. alteration in the height of the flame produces about one per cent. error in the light; it is therefore hardly necessary to increase the height of the flame by 40 per cent. to obtain a measureable variation.

As was pointed out in the original paper, the results though incomplete give some basis for the belief that if the Violle platinum standard is properly set up, and the experiments carried out according to uniform directions, its constancy will be greater than that of any other known source of light. Unfortunately it is not possible to push the experiments any further without considerable expense, and if the few hundred pounds necessary for the work are not available it will be far preferable to discard the Violle standard at once (as far as this country is concerned), and concentrate all available energy on the improvement of one of the less expensive standards.

Before closing, may I be allowed to join with the previous speakers in thanking Dr. Fleming for his paper, which for many years to come will be used as a work of reference by all those engaged in photometry.

The Chairman.

The CHAIRMAN: I think we are very much indebted to Dr. Fleming for his paper. I should like myself, as it is an old subject of mine, to have talked on it nearly as much as Prof. Ayrton, but I will spare you that infliction, and call on Dr. Fleming to reply.

Dr. Fleming.

Dr. FLEMING, in reply, said: At this late hour of the evening I shall not attempt to reply in detail to the many criticisms which have been passed on the paper. When I offered the paper to the Institution I felt sure it was a subject on which there would be a good deal of difference of opinion, even if not strong feeling, and that at any rate we should have an animated debate. That expectation has not been disappointed. In fact, it has been interesting to notice in the course of the debate how very much difference of opinion there has been, and

Dr. Fleming, how much that has been approved by some has been condemned by others. On the evening on which the paper was read I think the discussion dealt with purely scientific matters. I was anxious that the questions placed before you should not be merely questions of detail, and that the debate should not resolve itself merely into a discussion of the advantages of one or other form of photometer, or method of photometry, but that some of the broad and fundamental questions should be discussed. The points which are really important are not whether one person can compare a red and a green light within 0·5 per cent., whereas others cannot do it within 50 per cent., but they are whether our methods of photometry, or the things that we measure and define, are really the things that should be measured and defined. The real things that I was anxious should be discussed were questions of a more fundamental nature. For instance, in walking along the street you cannot but notice the immensely different effects that are produced by arc lamps, open or enclosed, flame arc lamps, gas lamps, and by every other kind of illuminant, and the question must force itself upon your attention, whether the so-called candle-power *is* a measure of the value of that particular illumination for the purpose of vision—in other words, of its power to enable us to see. Supposing you put the question to a non-technical person whether a particular room or street was well lit. What would he do? He would take out a newspaper and see if he could read, and if he could read he would say it was good. In that we are not concerned at all with slight differences of colour. The question of whether you can compare a red and green lamp within a fraction of 1 per cent. is immaterial when we regard it from the point of view of practical engineering. On the way home to night, in the railway carriage, you will not be concerned with the recognition of the precise difference in tint or colour between a *Westminster Gazette* and a *Globe*, so far as the paper is concerned, but what you are concerned with is, whether you can discriminate the print. If you can you say the illumination is all right: if you cannot, you say something appropriate. That is the reason why I laid stress on a method of discrimination as a method of determining the relative values of the illuminating powers of two lights. On the other hand the question of the colour quality of a light is very important indeed for certain purposes. I had hoped that from so great an authority as Sir William Abney we might have heard something which would guide us in arriving if possible at a way of distinguishing the colour revealing property of illuminants so as to define precisely their suitability for illuminating, say, a picture gallery or a dye-house. This is something quite different from "candle-power." If a central-station engineer were to ask a shopkeeper what candle-power he requires outside his shop the shopkeeper would say he does not know anything about candle-power. What he wants is such a light as will render the goods in his window as visible as, or more visible than, they are by daylight, and if he secures that he secures all he requires, and I do not think our ordinary measures for candle-power do give a numerical value to an illumination of any kind which would enable us to decide that question. I must not take advantage of your indulgence to go now into the

different objections that have been raised. I will simply conclude by thanking you for the kind reception you have given to the paper. I was very much pleased at the ready welcome which was accorded to it by the President and the Council when I first offered it, as I felt sure that whatever might be the merits or demerits of the paper it dealt with a subject which should be discussed, and that we should have an interesting discussion on it, and I feel on the whole that that hope has been fulfilled. Dr. Fleming.

(*Communicated*): I am glad to have the opportunity of adding a few words more by way of reply to the discussion on my paper, as, owing to the lateness of the hour, the time afforded me at the end of the debate was rather short. In so doing I will not deal with the remarks of each speaker separately, but will group them under the several headings of the subject matter of the paper.

First as regards Standards of Lights. There seems to be a general consensus of opinion that the "candle" is now merely the name for an arbitrary unit of light, and that as far as the British candle is concerned, it is best represented either by the Hefner lamp with the flame height increased 14 per cent., or by the 1-candle Pentane lamp of Mr. Vernon Harcourt, or otherwise that 10-candle power is best represented by the new Vernon Harcourt 10-candle standard. On the other hand, the British standard "candle" considered merely as a unit, does not agree with those adopted in France and Germany. Some have agreed and some differed with my suggestion to substitute a larger unit called the "lamp" for the candle. Whether this suggestion is ultimately adopted or dismissed, I still hope that it may be possible to establish an International Unit of Light which may be called by a generally accepted name, whether the "International Candle" or the "International Lamp," or some other term; and that this convention will abolish the existing differences. At the present moment, an English 10-candle glow-lamp, even if correctly marked, is not identical with a French 10-candle or a German 10-candle lamp in actual luminous intensity, apart from errors in photometry.

Next as regards fundamental standards. I was glad to hear from Dr. Glazebrook that this matter is receiving his attention, and he will have seen from the remarks during the discussion the necessity that exists for some final standard of reference. I trust therefore it will not be long before the National Physical Laboratory will be in a position to make authoritative decisions upon this subject.

As regards working standards, many speakers have declared their preference for the amyl acetate lamp. The criticism that this lamp is less affected by barometric pressure than the pentane lamp is not, I think, valid, as it rests only on Liebenthal's experiments with an old form of pentane lamp, and not on experiments made with the present 10-candle Vernon Harcourt Gas Referee standard. There is room in this matter for further research.

With respect to my Large Bulb Glow Lamp Standards, two remarks were made which deserve attention—one by Mr. Trotter, who pointed out a possible error due to reflection from the back of the bulb. Although this objection was present to my mind, yet owing to the

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method that I have adopted of using the lamps at a constant distance from the photometer, it has never been found to be a serious cause of error. But with a view to its removal, I propose to place a dead-black mica screen inside the bulb behind the filament, and this, I think, will be done in the lamps of this pattern which will be issued by the Edison and Swan United Electric Light Company.

Another useful criticism was made by Mr. J. T. Morris, who gave some figures showing the effects of a rise in the surrounding temperature on the candle-power of a lamp. This effect unquestionably exists. Since the rate of radiation of the filament depends on the difference between its own temperature and that of the enclosure, any rise in the temperature of the surrounding enclosure must diminish the rate of radiation of the filament, and therefore if the voltage on it is kept constant, the temperature of the filament will rise and its candle-power will be increased. It will be necessary, therefore, to mark on every standard lamp the temperature at which its candle-power standardisation was effected.

A large amount of discussion turned on the merits of various photometers. These are largely matters of personal preference and opinion. Some prefer a Rumford photometer, which requires binocular vision, and others a photometer such as the Lummer-Brodhun, which demands monocular vision. Some men shoot best with both eyes open and others with only one eye open. I do not think it can be laid down as an absolute rule that binocular methods are better than monocular. A person with one eye defective, but the other good, may yet do accurate photometric work. As a matter of fact, we all "see" a little more with one eye than the other. No one need allow the reading of a Lummer photometer to be vitiated by stray light if proper precautions are adopted, hence the contention made that the Rumford in that respect is not so liable to error is not based upon an inherent defect of the Lummer-Brodhun photometer.

With respect to methods of photometry, I have been accused of confusing acuteness of vision with the determination of brightness. I was under the impression that I had tried to explain this difference in my paper, and had pointed out that measurements involving acuteness of vision were different from those depending upon the sensation of brightness. At any rate I threw out a suggestion on that point, but although Sir W. Abney and Professor Ayrton have both criticised me on this point, they have not told us precisely what is the difference in their opinion. The words "luminosity" and "candle-power" are used by some writers on photometry in a very confusing manner, and it was in connection with these outstanding and difficult questions that I had hoped we might have been able to clear the air during this discussion. I purposely raised the question whether the so-called "candle-power" is a true measure of the real value of the light for visual purposes. This question has been rather evaded during the discussion. Speakers have gone off on all sorts of side issues, such as whether the commercial lamps are properly marked for candle-power, whether red and green lights can be photometered with as much accuracy as white lights, whether voltage and current can be best measured by a potentiometer or by other

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instruments, which are all, no doubt, interesting matters, but they do not touch the questions lying at the basis of photometry.

I am glad to find my statements as to the great differences between the photometric measurements of lamps by different observers are supported by Professor Ayrton, out of his large experience. The notion that lamps can be shot through a photometer room at the rate of five thousand a day and accurately photometered is, I suspect, at the bottom of a good deal of the worthlessness of much commercial marking of lamps. The manufacturer wants to get a certain watts per candle, and the candle-power is marked almost at a guess to make it fit in with the value of the marked voltage and the current. Mr. Moul thinks the potentiometer is very "pretty in theory," and confidently states that a D'Arsonval galvanometer—whatever he may mean by that—"answers every requirement" for the measurement of lamps. He may be interested to know that the potentiometers are used at the Edison and Swan factory at my suggestion, and that I was not speaking at random in recommending it as the best method for measuring lamp voltages even in a factory.

As regards actual checking of incandescent lamps for station purposes and for customers, I strongly believe that the large bulb lamps I have brought to your notice will be found very convenient; if only station engineers and others will not conclude too hastily that any voltmeter is good enough by which to set them. It seems necessary to emphasise the fact that 1 per cent. variation in the voltage of a glow-lamp implies 5 or 6 per cent. variation in the candle-power. How many commercial voltmeters taken up at random can pass a test showing them to be accurate to less than 2 per cent.? They may be accurate when new, and not always remain so.

As regards the difficult question which arises in connection with heterochromatic photometry, some of the statements in my paper have been disputed, notably one connected with the so-called Purkinje phenomenon. If Professor Ayrton is right in contending that I am wrong, then he is under an obligation to explain the reason why such authorities as Von Helmholtz, Lépinay and Nicati, Blondel and others, have made assertions which conflict with his own experiments. How are these to be reconciled? These points, however, are confessedly difficult, and I have no wish to dogmatise upon them.

The advantage of bringing a paper before this Institution is that free and kindly criticism is given, and I can only in conclusion thank the Institution for the appreciation accorded to the material gathered for their discussion, and at the same time express the feeling that the paper has been the means of drawing from a number of authorities and experts much valuable information on this subject which will no doubt be read with interest and advantage by many who were not actually present at the debate.

The President.

The PRESIDENT: Gentlemen, I put it to you that we pass a very hearty vote of thanks by acclamation to Dr. Fleming.

The vote was carried by acclamation,

The President.

The PRESIDENT announced that the scrutineers reported the following candidates to have been duly elected :—

Associate Members.

Antonio Guitard. | Louis Tasman Reichel.
George W. Handley.

Associates.

Ralph Millar Crook. | Michael O'Sullivan, LL.B.
Gerard Ogilvy Nevile. | Alexander B. Robertson, Jun.

THE COMPANIES' ACTS, 1862 to 1900.

[COPY.]

SPECIAL RESOLUTION

(Pursuant to the Companies' Act, 1862, Sections 50 and 51)

OF

The Institution of Electrical Engineers.

Passed December 4, 1902, Confirmed December 19, 1902.

At a SPECIAL GENERAL MEETING OF THE MEMBERS ONLY of the above-named Institution, duly convened, and held at the Institution of Civil Engineers, 25, Great George Street, in the City of Westminster, on the fourth day of December, 1902, the following SPECIAL RESOLUTION was duly passed; and at a subsequent SPECIAL GENERAL MEETING of the Members only of the said Institution, also duly convened and held at the offices of the Institution, 28, Victoria Street, in the City of Westminster, on the nineteenth day of December, 1902, the following SPECIAL RESOLUTION was duly confirmed:—

RESOLUTION.

"That the Regulations contained in the Articles of Association of the Institution be altered in the following manner, that is to say:—

1. By cancelling Article 1 and substituting therefor the following:—

"1. The Articles of Association of the Institution of Electrical Engineers, as the same now exist, will remain in force up to and including the 31st day of December, 1902."

2. Article 2, by substituting "1903" for "1899," in the first and sixth lines, and "80" for "71" in the eighth line.

3. By cancelling Article 5 and substituting therefor the following:—

"5. Subject as hereinafter provided, on and after the 1st day of January, 1903, then existing Honorary Members shall continue to be Honorary Members, then existing Members shall continue to be Members, then existing Associate Members shall continue to be Associate Members, then existing Associates shall continue to be Associates, then existing Foreign Members shall continue to be Foreign Members, and then existing Students shall continue to be Students, subject to the obligations attaching to such various classes.

"The members of the different classes referred to as existing on the said 1st day of January, 1903, and such other persons as shall be admitted, in accordance with these Articles, and none others, shall be or become members of the Institution (either as Honorary Members, Members, Associate Members, Foreign Members, Associates, or Students, as the case may be), and be entered on the Register as such."

4. Article 7, by striking out the words "Foreign Members."

5. Article 12, by substituting "1902" for "1898" in the second line, and "30" for "25" in the third line, and inserting after the word "age" the words—

"Unless the Council shall be satisfied that there are sufficient reasons for admitting him to such class at an earlier age."

6. Article 13, by inserting the word "new" before and the words "(*i.e.* every Associate Member not on the Register of Associate Members on the 31st December, 1902)" after the words "Associate Member" in the first line, and by striking out the word "and" in the second line, and the words "whether admitted" to the letter "(b)" inclusive.

7. By striking out Article 14 and substituting therefor the following :—

"14. *Foreign Members*. Foreign Members shall be *foreigners* residing abroad who were on the Register of Foreign Members on the 31st of December, 1902."

8. By striking out Article 16 and substituting therefor the following :—

"16. Students shall be persons of any age who, at the time of election, are serving pupilage to an Electrical Engineer or Electrician, or who are studying Electrical Science at one of the Universities, Public Colleges, Technical Institutions, or Government Schools, or who otherwise satisfy the Council that there are special circumstances which, in the opinion of the Council, entitle them to admission. No person shall remain in the Class of Students after the 31st December next following the expiration of three years from the time of his election, unless at the expiration of such three years he shall not have attained the age of 20 years, in which case he shall be entitled to remain in the Class of Students until the 31st December next following the day on which he attains that age."

9. By striking out Article 18 and substituting therefor the following :—

"18. Except as hereinafter provided every candidate for election into the Institution, otherwise than as an Honorary Member or a Student, shall be duly proposed by a Member and seconded by another Member, in each case in writing and from personal knowledge, and his candidature shall be further supported in writing by not fewer than three Members or Associate Members.

"The Secretary shall thereupon submit the application of the candidate to the Council to be considered, and if it be approved by them, it shall be brought before the next General Meeting of the Institution, with the recommendation of the Council as to the class to which the candidate should be elected, for approval. But in the event of a candidate resident abroad not being personally known to a sufficient number of Members, or Associate Members, to enable him to satisfy the foregoing conditions of proposal, if such candidate be nominated by the Local Honorary Secretary of the Country or Colony in which he resides, and if sufficient evidence be produced to satisfy the Council as to the fitness of such candidate for election to any class, the Council may propose his election to such class, and no further support will then be necessary; but the proposal form of the said candidate shall be signed by the Chairman of the meeting of Council at which his candidature was accepted, and his application shall be brought before the next General Meeting of the Institution for approval.

"Every candidate for election into the Institution as a Student shall be duly proposed, in writing and from personal knowledge, by one Member or Associate Member. The Secretary shall thereupon submit his application to the Council, and if it be approved by them, it shall be brought before the next General Meeting of the Institution for approval."

10. By striking out Article 23 and substituting therefor the following :—

"23. The Council shall decide upon the application for transferring any candidate from one class to another, but, except as hereinafter provided, every candidate for transfer to any class shall be duly nominated for such transfer, in writing and from personal knowledge, by two Members; and his candidature for transfer shall be supported, in writing, by three Members or Associate Members. But in the event of a candidate for transfer resident abroad not being personally known to a sufficient number of Members or Associate Members, to enable him to satisfy the prescribed conditions of nomination, if such candidate can produce sufficient evidence to satisfy the Council as to his fitness for admission to the class to which he seeks to be transferred, the Council may accept, without further support, the nomination of the Local Honorary Secretary of the Country or Colony in which such candidate resides."

11. Article 24, by inserting the word "and" between the words "Members" and "Associate Members," and striking out the words "and Associates."

12. By striking out Article 26 and substituting therefor the following :—

"26. On election to the Institution every Member shall pay an entrance fee of three guineas, every Associate Member an entrance fee of two guineas, and every Associate an entrance fee of two guineas. On election to the Institution a Student shall not pay an entrance fee. When a person is transferred from one class to another he shall pay the amount of the entrance fee payable by a member of the class to which he is transferred, after deducting therefrom the amount of the entrance fee (if any) paid by him, and the amount of the fees (if any) paid by him on the previous transfer, or on previous transfers."

13. By striking out Article 27 and substituting therefor the following :—

"27. Except as hereinafter provided,
"Every Member shall contribute annually to the Institution the sum of three guineas ;
"Every Associate Member shall contribute annually the sum of two guineas ;
"Every Foreign Member shall contribute annually the sum of one pound ;
"Every Associate shall contribute annually the sum of two guineas ;
"Every Student under 19 years of age at the date of election shall contribute annually the sum of one guinea up to the end of the year in which he shall attain the age of 22 years, and thereafter annually the sum of one guinea and a half. Every Student of or above the age of 19 at the date of election shall contribute annually the sum of one guinea up to the end of the third year after the year in which he was elected, and thereafter annually the sum of one guinea and a half.
"Any Member residing abroad, or absent from the United Kingdom * of Great Britain and Ireland, the Isle of Man, and the Channel Islands, for nine months in any year, and giving previous notice in writing to the Secretary of his intended absence, shall, during the period of his absence, contribute annually the sum of two guineas. Any Associate Member or Associate so residing or absent abroad, and giving previous notice of his absence as above required, shall during the period of his absence contribute annually the sum of one guinea and a half."

* Wherever in these Articles of Association the term "United Kingdom" is hereinafter used, it is to be understood as including the United Kingdom of Great Britain and Ireland, the Isle of Man, and the Channel Islands, and the term "abroad" is to be understood as including any place situate beyond these limits.

14. Article 28, by inserting the words "while residing there" after the words "Eleven Pounds or," "Fifteen Pounds or," and "Two Pounds Ten Shillings or," respectively.

15. By striking out Article 29 and substituting therefor the following :—

"29. A Foreign Member who has not compounded shall, if he come to reside in the United Kingdom, while resident in the United Kingdom pay an annual subscription of three guineas."

16. By striking out Article 30 and substituting therefor the following :—

"30. An Associate who has compounded by payment to the Institution or its predecessors of ten pounds or of twelve pounds ten shillings, shall, if transferred to the class of Members, either directly or after passing through the class of Associate Members, pay an annual subscription of two guineas while resident in the United Kingdom, or of one guinea while resident or absent abroad as specified in Article 27 ; if transferred to the class of Associate Members he shall pay an annual subscription of one guinea while resident in the United Kingdom, or of ten shillings and sixpence while resident or absent abroad as specified in Article 27. Provided always that if such a Member compounded while an Associate and while resident abroad, and was admitted a Member before the 31st December, 1898, he shall pay no subscription while resident or absent abroad as specified in Article 27.
"Provided further, that any such Associate may compound for his annual subscription by payment of an additional composition equal to the difference between the composition he has already paid and the composition that he would have to pay if he had not compounded as an Associate.
"A Student, or an Associate, Foreign Member, or Associate Member, who has not compounded, shall, if transferred to a higher class, pay the same annual subscription as if he had been elected to such higher class on the day upon which he was transferred thereto."

17. By striking out Article 32 and substituting therefor the following :—

"32. Every Member, Associate Member, Associate, and Student, shall pay the annual subscription for the year in which he is elected, without reference to the period of the year at which his election takes place ; but he shall be entitled to receive a copy of all numbers of the "Journal" containing the proceedings of that year, and to such other publications of the Institution which may have been issued during that year, as the Council may from time to time determine."

18. By striking out Article 37 and substituting therefor the following :—

"37. The Council may in any special case where in their opinion it is desirable to do so reduce or remit the annual subscription, or the arrears of annual subscriptions, of any Member, Associate Member, Foreign Member, Associate or Student."

DUBLIN LOCAL SECTION

A HYDRO-ELECTRIC PHENOMENON.

By F. GILL, Member.

(Paper read before the Local Section Nov. 21, 1902.)

In June last one of the employees of the National Telephone Co. was working on a pole supporting a number of wires (17) running through a rural district near Glasgow. On touching the topmost wire the man received a severe electric shock. On reporting the matter to a member of the Engineer-in-Chief's staff, Mr. Watts, the matter was investigated, and it was found that during certain times sparks could be drawn from the wire in question. This wire was found to be an unused one, and was of copper weighing 100 lbs. per mile, about 1,000 yards long, and insulated at both ends and over its whole length. It was carried at a height of 26 feet from the ground, and its capacity would be about ·0087 m.f.d.

It was at first difficult to explain the reason for the charge as the wire seemed perfectly insulated from all other conductors. The only thing at all unusual about the line was found to be at a point where the exhaust steam from a colliery engine was blown from a distance of about 23 feet by the wind against the wires. The exhaust pipe extended vertically 18 feet and was 3 inches diameter at the top. It was found that the charge only occurred when the engine was working on load, and only when the wind blew the exhaust steam against the wire. Further investigation was made by Mr. Watts, who had a collector constructed of a long bamboo rod with an insulator at the top on which was fixed a number of short pieces of wire with a V.I.R. covered wire connected as a lead to the ground. When this collector was held in the steam near the mouth of the iron exhaust pipe a series of sparks was obtained from the covered lead, and the origin of the charge completely located. The weather during these experiments was exceptionally dry, and the charge could not be obtained on damp days.

Since that date Professor Magnus Maclean of Glasgow, having had his attention drawn to the phenomenon by Mr. Valentine, the Company's District Manager, has conducted some experiments by means of a portable electrometer. He found that when a similar collector to that already mentioned, but with the lead wire terminating above the ground, was inserted near the steam, continuous sparks of from ½ in. to ¾ in. long could be obtained between the end of the lead and a metal rod driven into the ground, the best results being obtained when the pressure of the escaping steam was highest. This length of spark would indicate a potential difference of about 40,000 volts. Professor Maclean also took sparks from the lead through his body and noticed that the physical pain experienced was much more severe than from a spark due

to about 100,000 volts' pressure derived from a large 24-plate Wimshurst machine.

Professor Maclean also tested the potential of the air 6 feet above the ground and found when under the issuing steam and about 12 feet from it some 1,100 volts, and at a point 30 feet from the steam about 900 volts, when the engine was working. The electricity generated was positive in each case. Of course, the hydro-electric effect of steam under pressure is well known and has been investigated by Faraday and by Armstrong, but it is very seldom that the effects are seen in the natural order of things.

MANCHESTER LOCAL SECTION.

HIGH TEMPERATURE ELECTRO-CHEMISTRY: NOTES ON EXPERIMENTAL AND TECHNICAL ELECTRIC FURNACES.

By R. S. HUTTON, M.Sc., Associate, and J. E. PETAVEL, Associate Member.

(*Paper read at Meeting of Section, November* 25, 1902.)

Although a few pioneers like Siemens and Cowles foresaw the importance of the application of the electric furnace to chemical problems, it is only within the last ten years that most of the important processes have been developed. With the discovery of calcium carbide in 1892, the commercial possibilities of making use of the extreme temperature produced in the electric arc seem to have first forcibly impressed themselves both on the chemist and engineer, and the demands for power thus created brought into existence all over the world large generating plants of which Niagara is a typical instance. In the early days Cowles found great difficulty in obtaining an electric plant of sufficient power for his purposes,[1] but soon the electrical engineer, realising the nature of the demands made upon him, was fully able to cope with them. The provision of cheap power has in turn reacted in stimulating the development of many new chemical industries. The magnitude of the present development of electric power for chemical purposes is clearly brought out in the statistics published by Swan.[2] It is usual to explain the very small progress of electro-chemistry here as compared with other countries by invoking the well-worn excuse that comparatively little water power is available in Great Britain. This subject is worthy of much closer attention than has been given it in the past. In the first place it is well to remember that in a great number of cases the cost of power is only a small percentage of the prime cost of the manufactured material. Again, the water power is frequently most inaccessibly situated, thus raising very considerably the cost in freight on raw material and finished product.[3] Owing to the improved efficiency of the steam engine, and to the huge progress made recently in the application of the gas engine to large powers, the cost of energy derived from coal is daily

[1] Crompton, *British Assoc. Reports*, p. 809 (1888).
[2] *Journal Soc. Chem. Industry*, vol. 20, pp. 662–676 (1901). See also Borchers, *Die Elektrochemie auf der Weltausstellung in Paris*, 1900. Halle a. S.
[3] Report of Arrhenius to Swedish Government, see *Electrician*, vol. 47, p. 71 (1901).

becoming less,[1] and is already capable of competing successfully with the less favourably situated water powers.

There is, indeed, no valid reason why many of the electro-chemical industries should not be a success in this country. As will be seen later, a considerable number of electric furnace products are absorbed directly by the iron and steel industries, which of all manufactures in this country are probably the most favourably situated for obtaining cheap power. The manufacture of the alloys of the rarer metals, either in direct connection with some existing steel works, or at any rate in these districts, should offer every economical advantage; moreover, in these cases the raw product forms a very large proportion of the total cost. Much has been written of the future which has been opened up by the application of producer and blast furnace gases,[2] but even if we were to consecrate our whole time to the importance of this subject in its bearings on the electro-chemical industry, we could hardly do it justice. We will therefore pass directly, first to the consideration of the subject in its experimental stage, and then follow it in some of its commercial applications.

PART I.

Experimental Equipment.

In considering the equipment of a laboratory for experimental work in Electro-Metallurgy, the point of utmost importance should be, in the first place, to provide power to enable the experiments to be carried out on a reasonably large scale. The actual magnitude of the power equipment must be regulated by two principles. It is very desirable that the experiments though not on a scale directly comparable with the commercial process should, nevertheless, be of sufficient magnitude to furnish reliable practical data. On the other hand, as the question of cost has unfortunately to be considered, it is necessary to keep the equipment within certain limits, so that any given experiment can be repeated frequently under all possible conditions. Such work will supply not only valuable scientific information, but also the necessary data for practical application. Having said thus much with regard to the scale of the work, let us consider what should be the main points governing the choice of equipment. As we shall see later, the variety of different forms of electric furnaces which have been proposed or used is extremely great, and it would be altogether impossible to provide in any laboratory, however large or wealthy, even the most important of these. With regard to the generating plant the same may be said. In commercial work we find conditions varying from the 15,000-volt nitric acid plant down to the 4 or 5 volts required by the zinc or aluminium processes; from the continuous current used in all electrolytic work, to the mono- or multi-phase alternating current employed

[1] Humphrey, *Proc. Inst. Mech. Engineers*, 1901, pts. i. and ii., p. 41; *Brit. Assoc., Sect. G., Belfast* (1902).

[2] Bryan Donkin, *Min. and Proc. Instit. Civil Engineers*, vol. 148, pp. 1–55 (1902).

in the purely electro-thermal reactions. Our object therefore must be, not to establish a limited number of definite examples, but to obtain an equipment extremely flexible so that without serious expense any of the conditions required by such work may be obtained. It is unfortunately rarely possible to turn an ideal into a concrete fact; the development of a laboratory must necessarily be gradual, each year bringing alterations and improvements. Nevertheless a description of the actual equipment of the electro-chemical laboratory of Owens College may be of some value to those interested in the subject either from a commercial or theoretical point of view. The motive power at present available is rather insufficient, but hopes are entertained that it may before long be increased. It consists of a gas engine and motor which can be coupled on to the same driving shaft, and together are capable of developing a nett output of 30 to 40 k.w. The generating plant comprises several different types of machines.

One unit of 40 k.w. is capable of being connected so as to give any electromotive force between 10 and 200 volts, the maximum current being 600 amperes. This dynamo is used for arc furnace work. Further, a dynamo specially intended for electrolytic work, capable of giving 1,000 amperes at 15 volts. With regard to alternating currents, a 40-k.w. three-phase and a 20-k.w. single-phase machine are provided. The latter can be connected so as to give anything between 30 amperes at 600 volts and 250 amperes at 75 volts. Finally, plant used some time ago by Mr. McDougall for the manufacture of nitric acid was presented by him to the laboratory. It will give alternating current up to 16,000 volts. Passing now from the dynamo house to the electro-chemical laboratory itself, the first problem is the exact regulation of these comparatively large currents, since for satisfactorily studying some of the electrolytic processes it is absolutely essential to have the current entirely under control. The diagram of the series resistance used for this purpose is shown in Fig. 1; as will be seen a number of switches are provided, by means of which successive portions may be short-circuited.

This resistance is divided into two parts, the first of manganin wire designed particularly for starting an arc furnace, and capable of being used for currents up to 300 amperes; the second consisting of German-silver tubes, water-cooled, and with maximum carrying capacity of 1,000 amperes. After some consideration the water-tube resistance was chosen as being the most suitable for regulating large currents,[1] and as this subject is of some general interest we venture to give details of the design and of the behaviour under actual working conditions. The design of the water-tube frames is shown in Fig. 2, which gives a general view of the frames, and Figs. 3 and 4 giving detail of the design of the terminal pieces. The frames are of two types, the first being made of parallel ¼-inch tubes for currents of 600 amperes and below. As will be seen, these tubes are let into ½-inch by 1-inch gun-metal strips, which are fixed on to wooden frames; each strip carries two ⅜-inch set screws serving as terminals. One of these is used for the permanent leads, the other is useful to fix any temporary

[1] See also *Zeitschr. für Elektrochemie*, vol. 8, pp. 6, 58, 123, 124 (1902).

connection. The second type of frame for 1,000 amperes consists of two ½-inch German silver tubes, 6½ feet long, connected in series, and has a resistance of 0·024 ohm. The terminals shown in Fig. 4 are similar to those just described, but more massive. Two sliders are provided of the design shown in Fig. 5, by which the actual resistance in circuit can be varied, and the current adjusted with accuracy to the value desired.

As will be seen, there is a stiff central spring, by means of which the sliders are kept in contact with the tubes during adjustment. They can be clamped in any given position by two thumb-screws. In considering the maximum power which may be dissipated in a water-tube

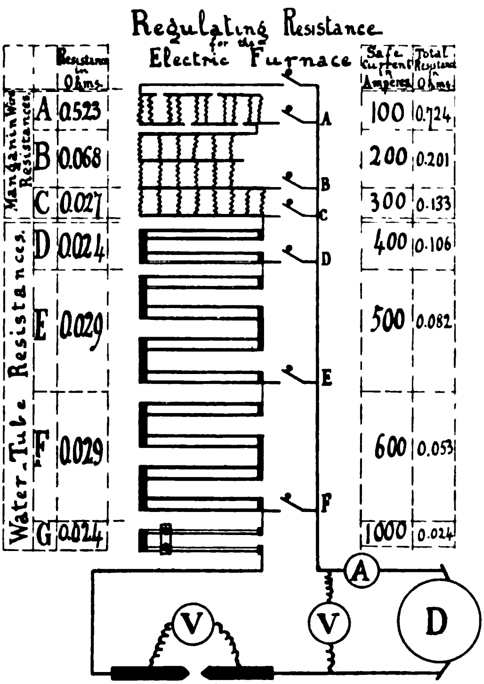

FIG. 1.—Diagram of Regulating Resistance for Electric Furnace.

Frames A, B, C, are manganin wire resistances, and together with the corresponding switches are mounted on a stand fitted with rollers. The other frames consist of German-silver tubes fixed permanently to the wall and provided with a water circulation. D is made of ½-inch tubes about 4 feet long, and 0·025-inch thick, E and F of ½-inch tubes 3 feet long and 0·03 inch thick, whilst G is of ½-inch tubes 6½ feet long and 0·02 inch thick.

resistance we are concerned with two principal factors. Firstly, the maximum rate at which water can be passed through the tubes; secondly, the maximum rate at which heat can be transmitted from the metal to the water. In all practical cases the first limiting factor will intervene long before the second would show its influence. The

design of the water-tube frame will therefore depend on the dimensions of the tube and the available head of water. As a general guiding factor we may say that a flow of one litre per minute will dissipate up to 2½ k.w.[1]

Close to the water-tubes a resistance is provided by which the exciting current of any of the dynamos can be most effectively

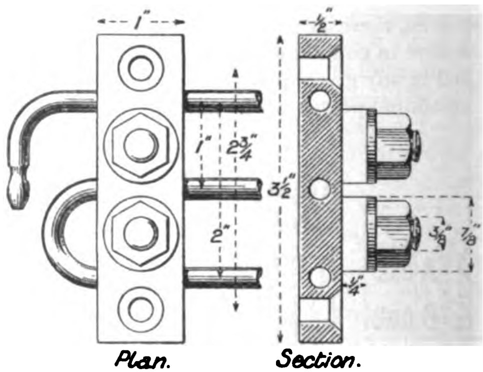

FIG. 3.—Terminals of Water Tube Resistance. (600 Ampere Frame.)

The German-silver tubes are soldered into gun-metal strip carrying two ⅜-inch bolts. The water passes in series through several tubes, connections being made by means of a U tube as shown in the figure. The gun-metal strips are mounted on wooden frames.

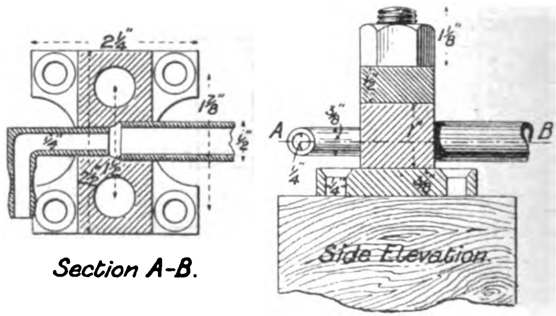

FIG. 4.—Terminals of Water Tube Resistance. (1,000 Ampere Frame.)

Gun-metal castings form the mounting for the German-silver tube, and carry two ½-inch bolts by which the connections are made.

regulated; it is in constant use for the considerable variations of voltage necessary during the progress of some of the furnace operations. We now come to the actual furnace equipment and the different types of apparatus which are best adapted for laboratory work. Foremost

[1] The larger tubes are distinctly the more satisfactory, since in this case there is no difficulty in obtaining an efficient flow of water from the ordinary supply. With the smaller tubes it is necessary to have numerous inlets and outlets, as their resistance to the flow of water is considerable.

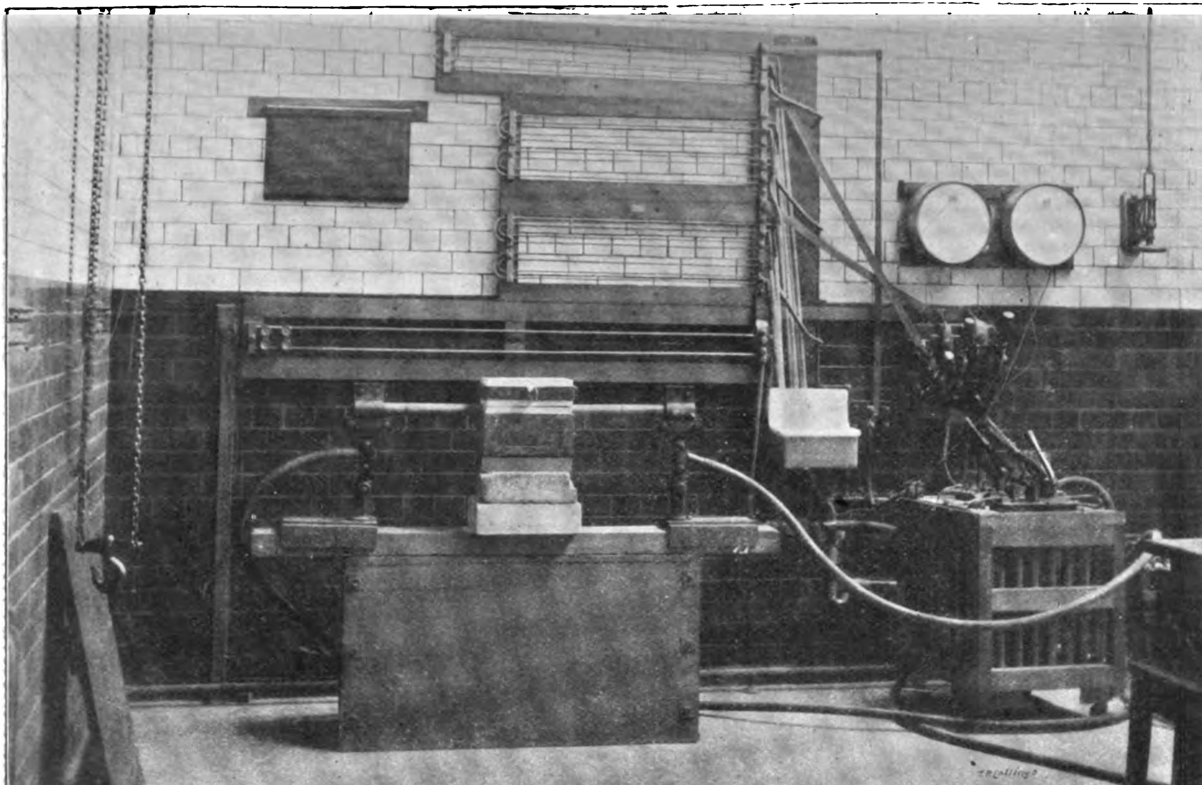

FIG. 2.—Regulating Resistance fitted for 40-kw. Moissan Furnace.

To the right is the portable resistance, and above the 500, 600, and 1,000 ampere short-circulating switches. Bare copper strip $1\frac{1}{4} \times \frac{1}{4}$ and $2 \times \frac{1}{4}$ inches connect these switches with the different frames seen in the centre. The two carbons are carried in massive copper holders which can be adjusted to any given height, the leads being bolted to the vertical standard of the holder of $2\frac{1}{4}$ square inches cross section.

amongst these must be placed the Moissan furnace.[1] A dimensioned drawing of this type for a power of about 40 k.w. is given in Fig. 6. Taking into consideration the many discoveries made by Moissan in the course of his investigations, it is surprising that as yet only a very small percentage have found commercial application. The reason of this may, perhaps, be ascribed to the fact that this form of furnace, though proving itself eminently suitable for the pioneering work for which it was intended, scarcely gives any data on which a technical process could be founded. It is, in fact, a striking example of how the apparatus most suited for purely scientific work is seldom capable of direct commercial application. It was not until the work was taken up by the practical engineer that the scientific discovery developed into a commercial industry. We shall see below that most frequently the financial success of a process has been in direct proportion to the mechanical improvements introduced, the chemical modifications being generally of secondary importance. It is therefore necessary to be able to provide a type of furnace corresponding in principle to the most usual technical forms, and thus carry out the experiments, if not on the same scale, at least in the same manner as would be done in the factory. Fig. 7 is a plan of an apparatus similar to that used by Haber,[2] which we have found extremely useful for representing many different forms of furnace. Connected as shown in Fig. 9A, it has proved itself most satisfactory for the manufacture of aluminium by the electrolysis of cryolite containing Al_2O_3, replacing the carbon block *C* shown in this figure by a small furnace built of loose bricks, a good example of a carbide "pot" furnace giving a most satisfactory yield of calcium carbide can be obtained. Frequently in the electrolysis of fused salts it is an absolute necessity to make the crucible lining of the material itself. This result is obtained (as shown by Muthmann, Hofer and Weiss),[3] by the use of a water-cooled crucible. The arrangement is shown in Fig. 9B. Whilst the vertical holder enables us to represent a large number of different types of furnace, those of the Acheson Carborundum type can be very simply built up by the use of ordinary materials. Fig. 10 shows a carborundum furnace as used with 40 H.P.

The next figure (Fig. 11) is a drawing of a furnace suitable for making calcium carbide or for other furnace operations. The design is inexpensive, and the apparatus most serviceable.

Such experimental equipment will be of importance not only from an educational point of view, but it is by no means impossible that certain of the difficulties in technical processes may be overcome by its use. It is important, however, not to neglect the purely scientific work, which, though it may possibly not find any direct application in the immediate future, has, however, frequently proved to be the starting-point of notable advances. In this direction the work in progress consists in the determination of the effect of gaseous pressures on high temperature chemical phenomena; it is proposed to study care-

[1] Moissan, *Le Four Électrique*, Paris, 1897.
[2] Haber, *Zeitschr. für Elektrochemie*, vol. 8, pp. 1, 26, 607 (1902).
[3] *Leibig's Annalen*, vol. 320, pp. 231–269 (1902).

fully some of the gaseous and other reactions which may be expected to differ considerably from those occurring under ordinary conditions. The apparatus shown in Fig. 12 is destined for work up to 200 atmospheres, and for currents up to 1,000 amperes, and has been provided out of funds received from the Government Grant Committee of the Royal Society.

PART II.

NOTES ON TECHNICAL PROCESSES.

In the comparatively short time which is at our disposal it would be altogether impossible to give any adequate account of the general development of the industry. We shall, therefore, neither touch on the historical side of the subject, which has already been fully treated by others, nor do we propose to give a complete account of the methods

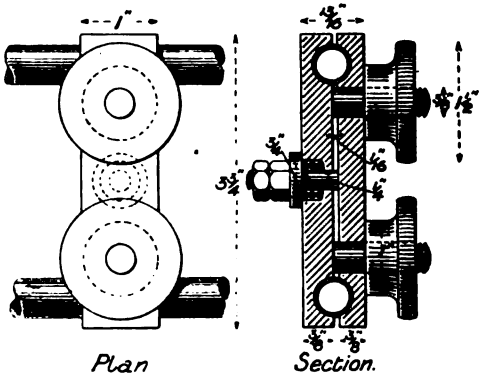

FIG. 5.—Sliders for 1,000-Ampere Water Tube Resistance.

These are used to regulate the larger currents, one being moved a short distance whilst the other remains fixed, this latter being in turn advanced. The E.M.F. on the moving slider is thus kept small and sparking avoided.

in use in such widely developed industries as calcium carbide, aluminium, etc. Our object will be more especially to consider some of the newer industries, to draw attention to recent advances in the older ones, and to consider where possible, the directions in which improvements are to be expected. In connection with each subject a few references are given which may be of interest to those desiring more complete information. In order to facilitate the description, a diagrammatic representation of the principal types of electric furnaces is given in Fig. 13.

CALCIUM CARBIDE.[1]—We have not here to deal with the economical

[1] Vivian B. Lewes, *Acetylene*, London, 1900; Moissan, *Comptes Rendus*, vol. 115, 1031 (1892), vol. 118, 501 (1894); Moissan, General Review of Chemistry of Carbides, *Rev. Générale des Sciences*, vol. 12, pp. 946–955 (1901).

side of the subject, but it may be said that the financial crisis through which the carbide industry has recently passed influenced very considerably its progress.[1] Previously the manufacture of carbide was being taken up in innumerable small factories with processes differing very largely as to their efficiency. The present circumstances have eliminated the less efficient methods, and the comparatively few firms which are still successful owe their advantage to the careful consideration they have given to the perfection of the mechanical details. Speaking generally, it may be said that the tendency, here as in other manufactures, has been to simplify the process as much as possible. The current regulation is automatic,[2] and is achieved either by raising the vertical electrodes when the "pot" type of furnaces are used, or by some other means of bringing more resisting material between the electrodes. Means are frequently provided for automatic grinding, weighing, and mixing of materials. With regard to the labour-saving problem, a continuous furnace possesses obvious advantages. A great deal of discussion has arisen with regard to the relative merits of the "continuous" and "discontinuous" furnaces, but this is largely due to a confusion of terms, since the tapping methods,[3] which undoubtedly give a poorer grade carbide, are by no means the only continuous ones; in fact with such furnaces as the Horry, Siemens and Halske, etc., all the advantages of a continuous process are attained, without the great loss of heat which is entailed by the removal of the molten carbide from the furnace. The production of calcium carbide being a purely electro-thermal operation, either continuous or alternating current can be used, but the balance of advantage seems to be decidedly in favour of alternating current, which lends itself more easily to long-distance transmission. An alternating plant is, moreover, more suitable to withstand the sudden and intense variations in load, which it is at times impossible to avoid, and the carbide produced is said to be more uniform in quality.[4]

Three-phase current, which has been employed notably at St. Marcello d'Aosta,[5] has the advantage of giving a more even distribution of temperature. It must be remembered that the most favourable temperature conditions are somewhat narrow,[6] and that too intense a heat can produce the phenomenon of "burning." Alternating current has, however, one serious disadvantage, namely, that the power-factor is somewhat low. Experience has shown that with a view to preventing both the inconvenience and loss caused by the dissipation of the finely divided material, it is necessary to have the furnace properly enclosed.

[1] A careful estimate recently made points out that of the 254,000 H.P. installed for this manufacture, only some 64,000 H.P. are in use. *Mineral Industry*, vol. 10, p. 74 (1902).

[2] *E.g.* Horry, *U. S. Patent* 655,779 of 1900.

[3] Carlson, *Zeitschr. für Elektrochemie*, vol. 6, pp. 413, 429 (1900); Frölich, *Zeitschr. für Elektrochemie*, vol. 7, pp. 1–10 (1900).

[4] Pradon, *Electrical Review*, vol. 49, p. 463 (1901).

[5] Cesare Pio, *Electrician*, vol. 43, p. 637 (1899); *Electrical World and Engineer*, vol. 40, p. 375 (1902); Bertolus, *Engl. Patent* No. 16,942 (1897).

[6] Rothmund, *Zeitschr. für anorganische Chemie*, vol. 31, p. 136 (1902); Borchers, *Zeitschr. für Elektrochemie*, vol. 8, p. 349 (1902).

This minimises to a large extent the oxidation of the carbon electrodes, which is also an important question with regard to cost, and further enables the gases to be made use of for heating purposes. There seems to be a distinct gain to be achieved by finely dividing and intimately mixing the raw materials, and in modern enclosed furnaces these appear now to give very little trouble.

The carbide industry has reached a large development in the United States, where at Niagara some 15,000 H.P. are continuously in use. Although the distance of these works from the power-house is only about two miles, it has been found economical to transform the 2-phase current generated at 2,200 volts, to 3-phase at 11,000 volts, the trans-

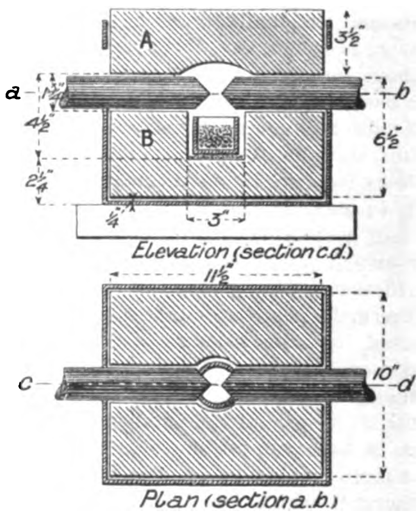

FIG. 6.—40-k.w. Moissan Furnace.

This is constructed of blocks of Monk's Park Bath Stone, which after trials with various limestones has proved to be the most suitable. The furnace is composed of two blocks, the first A, forming the cover, the second B, the furnace proper. This latter has two grooves of slightly greater diameter than the carbons to be used. As the blocks are apt to split under the influence of the heat, they are held together by iron bands; these are provided with sockets (not shown in figure) which enable the furnace or cover to be lifted by long iron bars. The central hole which may be of diameter 2½-4 inches, according to size of crucible in use, is lined at the bottom by a layer of powdered magnesia which prevents the carbon crucible coming in direct contact with the lime. An annular space should be left around the crucible, which not only facilitates the heating, but also prevents the lime and carbon from entering into combination.

formers being Scott connected and of capacity 2,500 H.P. At this pressure the current is received at the transformer-house close to the carbide works and transformed down, first to 2-phase 2,200 volts, then to 110 volts, at which it enters the furnaces.[1] At Saulte Ste. Marie, a sister factory for 20,000 H.P. is nearly complete. A plan of the Horry

[1] *Electrical World and Eng.*, vol. 34, p. 794 (1899).

furnace given in Fig. 15 is of some interest, this being the type of furnace employed in these works.[1]

Of other furnaces, those of Gin and Leleux[2] and the Deutsche Gold u. Silber Scheide Anstalt[3] are amongst the most widely known, the former having been fitted up at Meran and in some parts of France and Italy, whilst the German firm have equipped several factories in Norway and elsewhere. The condition of the carbide industry is at the present time entirely dependent on the progress of acetylene lighting, and despite the unfortunate reaction caused by the flooding of the market by improperly constructed generators, now that the subject has received due attention and safe and reliable apparatus are available,[4] steady progress is being made.

Possibly the application of acetone as a solvent for acetylene,[5] enabling it to be safely stored under pressure, may influence its future considerably.

Other proposals for the use of calcium carbide, which have not as yet come into general use, include its application as a metallurgical reducing agent,[6] and for the production of the finer grades of lamp-black.[7]

With regard to the efficiency of the manufacture, an important advance would undoubtedly result from any invention enabling the heating power of the waste gases to be more generally used for preliminary treatment of the raw materials. The combination of the lime kiln and the electric furnace would lead to a great economy of energy, but up to the present the practical difficulties have outweighed the theoretical advantage.

REFRACTORY METALS AND THEIR ALLOYS.—The difficulties in the way of the commercial application of the electric furnace having been successfully overcome in the case of calcium carbide, efforts were soon directed to the possibilities of producing some of the rarer metals on a large scale in a similar type of furnace. The valuable qualities of some of these metals in the manufacture of steels insured their finding a satisfactory market. Amongst these metals Ferro-Chromium takes an important place, chiefly on account of the large employment of chrome steels for the manufacture of armour plate, projectiles, tool steels, springs, etc. At the present time one factory alone in America is using 450 tons of 70 per cent. ferro-chromium a year for armour-plate work. For this country data are not easy to obtain, but doubtless, owing to the advanced state of the British steel trade, large quantities of these alloys are employed. The chief factories are situated in France and the United States. The Willson Aluminium Company, with works at Holcombs Rock, Va. and Kanawha Falls, W. Va., manufacture ferro-

[1] Horry, *English Patents* No. 22,521, 1897, and No. 14,261, 1899.

[2] Borchers, *Zeitschr. für Elektrochemie*, vol. 7, p. 236 (1900); Haber, *Zeitschr. für angew. Chemie* (1901), p. 185.

[3] Kershaw, *Electrician*, vol. 46, p. 267 (1900).

[4] *Report of Committee on Acetylene Generators* (Home Office), 1902.

[5] Fouché, *Soc. Française de Physique*, No. 171 (Nov. 15, 1901); *Journal de l'Electrolyse*, vol. 10, No. 122, p. 13 (1901).

[6] v. Kügelgen, *Zeitschr. für Elektrochemie*, vol. 7, pp. 541, 557, 573 (1901).

[7] Hubou, *Mémoires de la Société des Ingenieurs Civils de France* (1900).

chromium and other alloys, using some 3,000 H.P. at the latter works; the furnaces they employ are suitable for tapping, the metals being run into lined iron trucks, the automatic regulation as used in the carbide industry being also installed. Tungsten and ferro-tungsten, which have been used for a considerable time for manufacturing self-hardening and high-speed tool steel, can also be most satisfactorily manufactured in the electric furnace, and this product has considerable advantage in that it is in a compact fused form, and is thus less liable to oxidation in the process of adding to the steel. One of the most important of these alloys is Ferro-Silicon, the manufacture of which has been taken

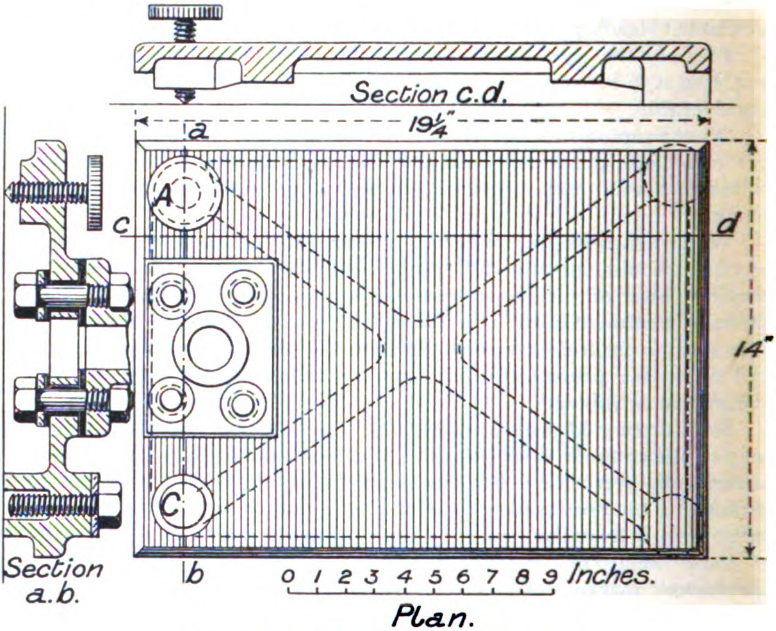

FIG. 7.—Vertical Electric Furnace Plan.

The apparatus consists of a cast-iron base, an adjustable standard, and a feeding gear. The base is ½ inch ruling thickness, strengthened with rims and cross-ribs 1 inch thick. At one corner a ¾-inch bolt C serves as a terminal. A is a levelling screw. The square base of the standard is insulated by a slab of vulcanised fibre, and held down by four ¾-inch bolts. See section A-B.

up in several of the factories in which calcium carbide can be no longer produced with sufficient economy. The grade varies considerably, from 15 per cent. up to 85 per cent. The chief application of ferro-silicon is in the casting of iron and steel, where it plays the important *rôle* of deoxidiser, thus getting rid of blow-holes, and at the same time, owing to the high heat of combustion, renders the metal more fluid for casting.

As to Copper Silicon, this has been prepared for a long time in the furnace of Cowles, and has found considerable application as a deoxidiser, and for increasing the tensile strength in copper and brass

castings. There seems every indication that Silicon itself will soon displace its alloys for some of the more important work, it is now prepared in considerable quantities by the method of Scheid.[1] Among the rarer metals which have not as yet received any wide technical application, we may mention Ferro-Titanium and Ferro-Vanadium. Owing to recent work these metals have been shown to have considerable technical value in the steel industry, and the difficulties connected with their manufacture have been largely overcome. According to Rossi, the addition of titanium to pig-iron of whatever quality produces a considerable increase both in tensile and transverse strength.[2] A similar but less marked effect is produced on steel. It is evident that when dealing with raw material of such high value as is the case with some of these rarer metals, it is very necessary to have an electric furnace in which the process can be kept well under control, and in which the loss of material can be minimised as much as possible; this result has been achieved by using a properly closed furnace. The development of the industry of the rarer metals has been most materially assisted by the beautiful discovery of Dr. H. Goldschmidt in which the metallic oxides are reduced by finely divided aluminium; the process is worked at Essen, by the Allgemeine Thermit-Gesellschaft. This method at first sight possesses advantages over the direct electric furnace treatment, since metals with very low carbon content can be easily prepared; but the refining of the metals in the electric furnace is by no means impossible of accomplishment,[3] and will doubtless come more into general use and be further worked out as the industry increases. On the other hand, the Goldschmidt method is so indirect —aluminium, itself an expensive electric furnace product, being used— that, provided a sufficient demand for any given metal exists, no trouble should be found in overcoming the few difficulties which remain for preparing a sufficiently pure material, by a much more economical and more direct method.

CARBORUNDUM.—This industry, although by no means to be compared with calcium carbide so far as power is concerned, is of considerable importance and illustrates a type of furnace which is finding many other applications. A photograph will be found in the early part of the paper, Fig. 10, which, though on a smaller scale, gives a very good idea of the general appearance of such a furnace. The industry has increased very rapidly, for whereas in 1893, 6¾ tons were manufactured, in 1901 1,690 tons were produced, and the power in use has just been increased (September, 1902) from 2,000 H.P. to 3,000 H.P., thus raising the output to some 2,690 tons. The manufacture of carborundum has often been described.[4] The raw materials which are heated together in a furnace of type E, Fig. 13, consist of coke and sand; a small percentage of sawdust and salt is added, the one to insure the porosity of the charge, the other to act as a flux. Carborundum, as is well known, has found large use as an

[1] Scheid, *Engl. Patent* No. 18,659 of 1899.

[2] Rossi, *Mineral Industry*, vol. 9, p. 715 (1900); Goldschmidt, *Zeitschr. für angew. Chemie*, Heft 28 (1902).

[3] Moissan, Refining Chromium, *Le Four Électrique*, p. 209; see also *Chemical Trade Journal*, vol. 30, p. 453 (1902).

[4] Kohn, *Journ. Soc. Chem. Industry*, vol. 16, p. 863 (1897).

abraisive, but of still more interest is its recent application in the steel industry, replacing to a considerable extent ferro-silicon. The importance of this development may be judged by the fact that the present consumption of carborundum for this purpose alone is 75 tons per month. Still more promise is shown by the proposed use of this substance for making highly refractory materials. In this connection the discovery of Fitzgerald of "recrystallised" carborundum, which is prepared by agglomerating the finely divided material and reheating in the electric furnace, should be noted, as also that of Tone for using for similar purposes the "amorphous" variety, which always forms a considerable proportion of the product. Each of the carborundum

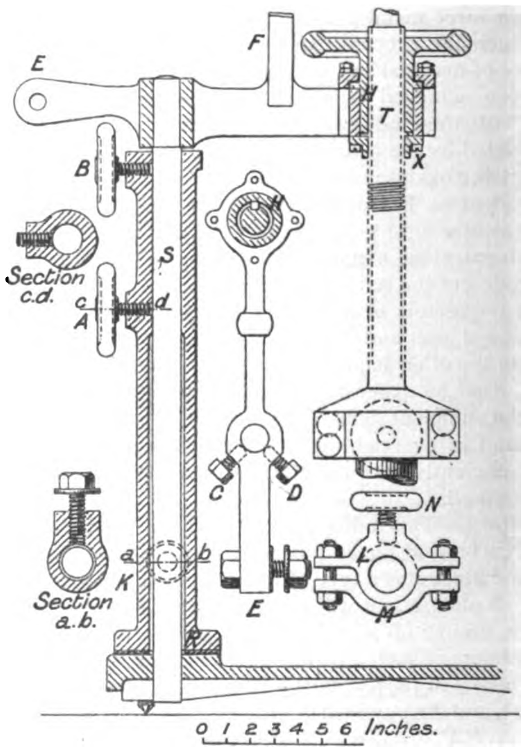

FIG. 8.—Vertical Electric Furnace Elevation.

A hollow cast-iron column R, 2½ inches diameter, is fixed on to the base shown in the previous figure but insulated from it, the height of the gun-metal cross-bar carrying the screw feeding gear can be adjusted within wide limits by means of the 1¼-inch steel rod S which is clamped in position by the hand wheels A and B. Connection can be made at either of the terminals K or E (the latter for currents above 600 amperes), the opposite pole being connected to the base. To avoid sliding contacts which would be objectionable for such large currents connection from the cross-bar to the screw carrying the carbon rod is made by means of four ½-inch flexibles not shown in this figure, but which can be clearly seen in Fig. 9. The gun-metal rod T, which carries the carbon, is 1½ inches diameter with a square screw thread (4 threads to the inch), giving a feed of about 1 foot; it is raised or lowered by means of a 7-inch cast-iron hand wheel. The design of the carbon holder is clearly shown, it is provided with rings of various diameter, so that carbons of very different sizes up to 3 inches can be held.

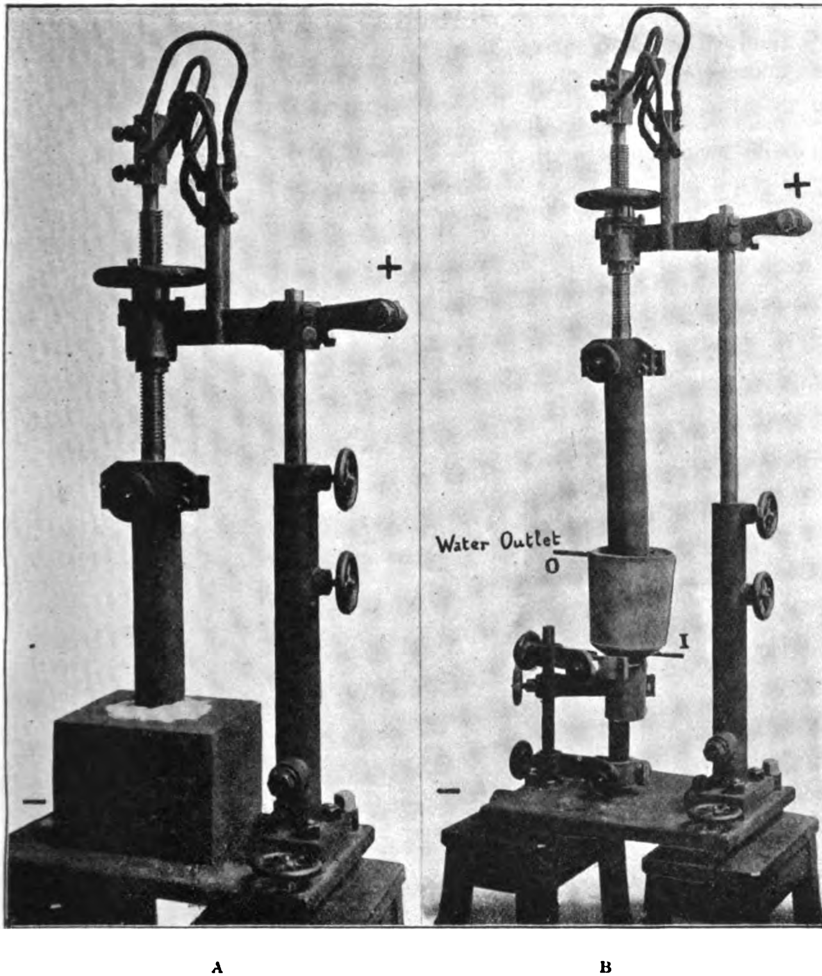

FIG. 9.—A. Experimental Aluminium Furnace.

This shows one way in which the vertical furnace, the design of which is shown in the previous figures, can be used. Upon the cast-iron base which forms the negative pole is placed a large block of carbon, having a cavity which serves as a crucible. The positive electrode is formed by a carbon 3 ins. in diameter, which is fed by the screw-gear described above.

B. Water-cooled Electrolytic Furnace.

Here the apparatus is fitted to be used for the electrolysis of fused salts; the water-jacket, by causing a layer of the fused mass to solidify, enables the electrolyte itself to form the crucible lining. This is frequently necessary, since with many substances it is impossible to find a furnace material capable of withstanding their corrosive action at the high temperatures which prevail. The negative pole is in this case formed by a vertical carbon, which is held in a clamp sliding on a gun-metal vertical rod fixed to the base.

FIG. 10.—Experimental Carborundum Furnace.

This is an almost exact reproduction of the commercial furnace on a small scale. It is built up of loose fire bricks on a cast iron base, the outside dimensions being 46 inches long, 28 inches broad, and 21 inches high. The electrodes, consisting each of two graphite plates 2[illegible] x 1 inch, are in contact with coke, which also forms the core connecting the two. This is a resistance furnace of type E shown in Fig. 13. The core is surrounded by the mixture of sand, coke, sawdust, and salt from which the carborundum is made.

furnaces in use at Niagara employs 1,000 H.P., the voltage starting at 200, and falling to 80 as the furnace heats up; the units are kept working at full power, the voltage being varied according to the progress of the reaction.

As is well known, the power is distributed by the Niagara Falls Power Company on the constant-pressure system, and it is therefore necessary to have some means by which this variation in the resistance of the furnace can be coped with. The two principal ways in which this can be accomplished are to change the ratio of the transformer, or to add in another small transformer which can be used as a booster; in either case it is necessary to deal with the primary, as the secondary connection for such large currents cannot easily be manipulated. Fig. 15 shows two of the most satisfactory ways of connecting for this purpose.[1]

ARTIFICIAL GRAPHITE.[2]—It was during the development of the carborundum industry that Acheson's attention was drawn to the formation of graphite in his resistance furnace, a discovery which has since been applied on a large scale. Artificial graphite had been known since the work of Despretz in 1849, and from a commercial point of view had been produced by the Girard and Street process, which consists in passing the amorphous carbon through the electric arc. The Acheson process, however, is capable of dealing with the material in larger bulk and gives a pure graphite, containing as little as one-tenth per cent. of ash. At first the work was limited to graphitising articles of agglomerated amorphous carbon. Such graphite electrodes are quite indispensable for the success of many of the aqueous electrolytic processes, both on account of their more compact nature and of their greater stability.[3]

It is generally considered that the presence of small quantities of metallic oxides is indispensable for the graphitisation of amorphous carbon; in fact Acheson has found that pure carbon submitted to the highest temperatures of his furnace remains untransformed. He has recently discovered, however, that there is no need for an intimate mixture of the carbon and metallic oxide, since the reaction can take place by a kind of cementation process if the two are roughly mixed together, the metal vapour easily permeating the material. The action appears to be a catalytic one, caused by the progressive formation and dissociation of metallic carbides, the presence of a small percentage of impurity thus being used time after time in the reaction. Girard and Street already in 1895 pointed out the part played by the metallic oxides in this reaction; they obtained, moreover, a fairly complete trans-

[1] Peck, *Electrochemical Industry*, vol. 1, p. 5 (1902).

[2] Despretz, *Comptes Rendus*, vol. 29, p. 709 (1849); Berthelot, *Ann. de Chim. et de Phys.* (iv.), vol. 19, p. 392; H. Moissan, *Le Four Électrique*, pp. 85–111; Girard and Street, *Engl. Patent* No. 13,340 of 1893, *German Patent* No. 78,926 of 1893; Street, *Soc. Intern. des Electriciens*, see *Electrician*, vol. 35, p. 542 (1895); E. G. Acheson, *U.S.A. Patent* No. 568,323 (1896); F. A. G. Fitzgerald. *Journal Soc. Chem. Industry*, vol. 20, p. 443 (1901); also *Journal of Franklin Institute*, Dec. 11, 1896; Borchers, *Zeitschr. für Elektrochemie*, vol. 3, p. 393 (1897).

[3] Sprösser, *Zeitschr. für Elektrochemie*, vol. 7, p. 971, etc. (1901); Förster, *Zeitschr. für Elektrochemie*, vol. 8, p. 143 (1902).

formation of the amorphous carbon into graphite. Moissan, who has minutely studied the formation of graphite, has found that its properties vary largely according to the method of production; but the question is by no means exhausted, and it seems probable, since the requirements vary from case to case, that a careful study of the influence of individual impurities upon the graphite produced, may lead to the preparation of electrodes still more suited for any particular electrolysis than those at present manufactured. More recently this method has been applied to the direct graphitisation of anthracite coals, with the production of a granular graphite, possessing very valuable properties for

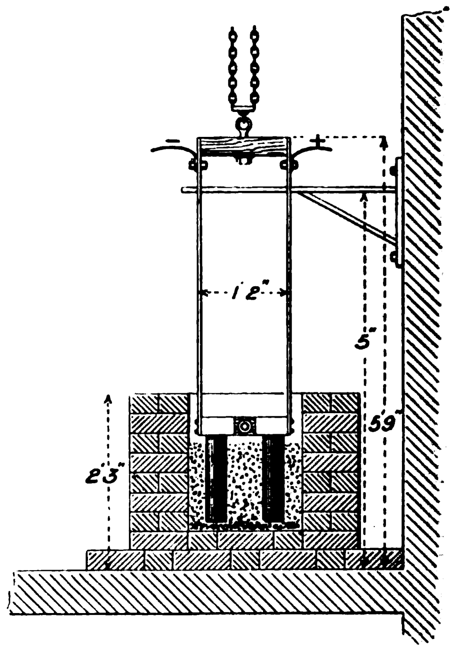

FIG. 11.—40-k.w. Experimental Carbide Furnace.

This represents a satisfactory and convenient laboratory form of the many and important technical furnaces of type C, Fig. 13. The two carbons, which are clamped side by side in a single holder but insulated one from another, are raised and lowered by means of a crane fitted to the wall. The current is led in by flat copper bars, which by sliding in grooves prevent any oscillation or side motion of the apparatus. The body of the furnace consists either as shown in figure, of fire bricks, or of a large cast-iron pot; in both cases the material itself forms the actual lining.

lubricating and similar purposes. Fig. 16 gives section of the furnaces used for graphitising electrodes. So as to increase the resistance of the furnace and reduce the intensity of current necessary, the electrodes are laid transversely and are surrounded by a mixture of coke and carborundum. On the other hand, the resistance of the anthracite being initially high, a small core of carbon is inserted. The resistance of the furnace falls with the progress of the reaction, but is

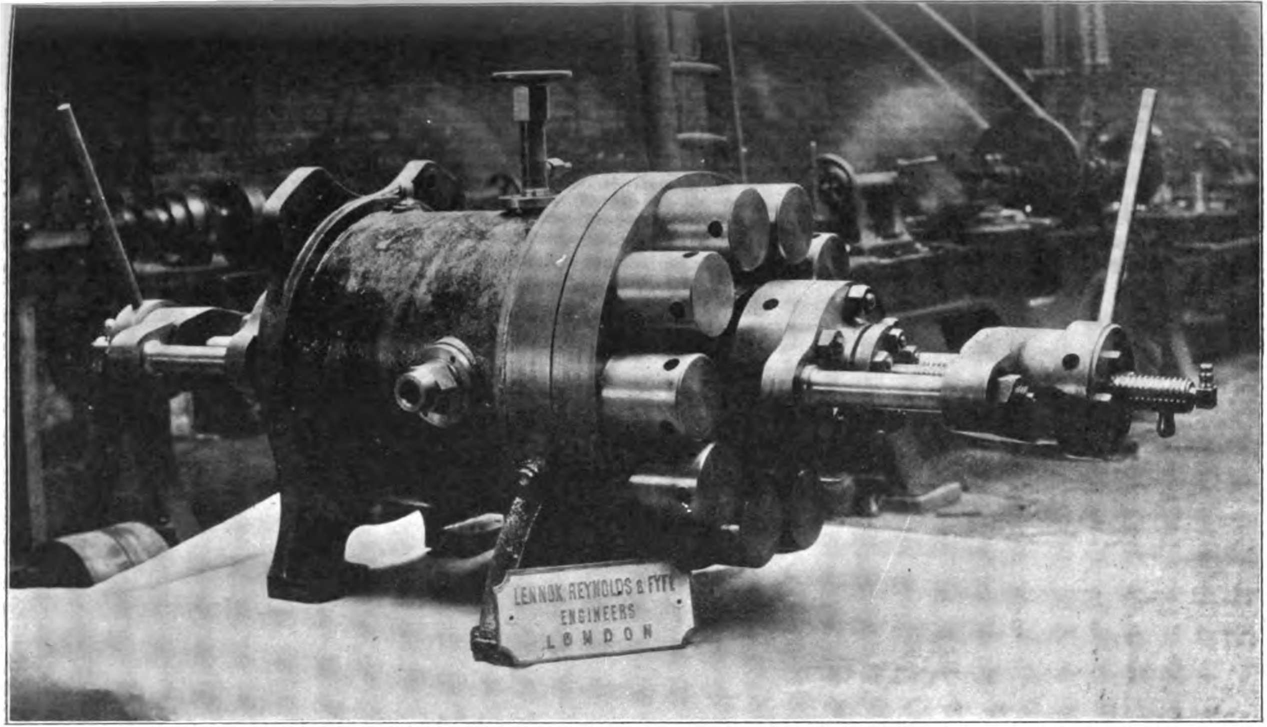

FIG. 12.—High-pressure Electric Furnace.

The apparatus is practically a steel enclosure, placed either horizontally or vertically, which can be used for any of the different types of furnace. It is air-tight, and designed for a working pressure of 200 atmospheres, being tested at 500 atmospheres. On the right and left will be seen the screw-gear by which the carbons are fed, whilst in front and behind are windows which will stand the full pressure, but which can be replaced by additional connections when a circulation of gas through the apparatus is desired. The main valve, which serves also to connect the pressure gauges, will be seen on the top. The apparatus is water-jacketed throughout, the refractory material of which the furnace proper is made being contained in a cast-iron lining, thus insuring the protection of the main forging. The construction of this apparatus has been carried out by Messrs. Lennox, Reynolds and Fyfe to the designs made at the College.

of course lower than in a carborundum furnace ; the system of regulation is similar. The transformers first installed gave up to 37,000 amperes at between 30 and 15 volts on their secondary circuit, the leads being properly interlaced to bring up the power-factor to a maximum. The frequency used at Niagara is as low as 25 $\sim$; it is probable, however, that in installing a generating plant solely for such chemical work, an even lower frequency would be preferred. By the graphitising process the conductivity is increased some fourfold ; the density is also changed, rising from 1·5–1·9 that of amorphous carbon, to 2·1–2·25 that of graphite. Apart from the question of conductivity an important advantage of graphite is the ease with which it can be machined. It can be cut and planed with ordinary wood tools, and screwed without any difficulty. The American production, starting with 162,382 lbs. in 1897, has increased to 2,500,000 lbs. in 1901, about half this being in the form of electrodes. 1,000 H.P. are employed in this manufacture, a number of furnaces being in use, each one in turn taking the full power ; the change over can be made in a few minutes.

We now pass to the consideration of aluminium, zinc, sodium, caustic soda, etc., which are primarily electrolytic processes, the heating effect of the current, though used to keep the cell in the molten condition, being of secondary importance. The electrolytic bath could of course in all cases be easily and more cheaply kept molten by means of an ordinary furnace, but these electrolytes are generally so corrosive in their action, that the wear and tear on the crucible would make such a process unworkable. The electrolyte when fused by the current itself usually remains solid around the walls of the furnace, and thus forms a protective layer.

ALUMINIUM.[1]—Since 1889 the only two processes in actual use for preparing this metal are those of Héroult and Hall, the former being confined to Europe, the latter to America. These two methods, the chemical and electrical nature of which seem to differ very little at the present time, consist essentially in the electrolysis of fused cryolite, to which Al_2O_3 is added as the separation of aluminium proceeds.

The type of furnace used in either case is that of D, Fig. 13, the carbon-lined crucible forming one electrode, the other being made up of a number of separate carbon rods. The differences between the two methods are essentially mechanical in nature ; it is not easy to obtain any detailed information, as no doubt the success of the process depends in each case upon the perfection with which some of the inherent difficulties have been overcome. The Hall process is worked by the Pittsburg Reduction Company, who have the largest output of this metal. At Niagara Falls, in the two works 10,000 H.P. are used ; at Shawinigan Falls some 5,000 H.P. ; whilst at Massena, N.Y., a new plant is being erected for 12,000 H.P. The cells in use consist of thickly

[1] Wallace, *Journal Soc. Chem. Industry*, vol. 17, p. 308 (1898) ; Becker, *Manuel d'Electrochimie*, Paris, p. 175 (1898) ; *Mineral Industry*, p. 14 (1892) ; Chandler, *Journal Soc. Chem. Industry*, vol. 19, p. 609 (1900) ; W. Murray Morrison, *Journal Institution of Electrical Engineers*, vol. 31, p. 400 (1901) ; Haber, *Zeitschr. für angew. Chemie*, p. 215 (1901) ; Richards, *Electro-Chemical Industry*, vol. 1, p. 49 (1902).

carbon-lined cast-iron pots 6 feet long × 3 feet wide × 10 inches deep; these form the cathode in which the metal is collected. The anodes are some 40 in number, and each carries about 250 amperes, the E.M.F. being 5 volts; thus some 65 H.P. are absorbed in each cell, a number of the cells being connected in series.

So far as the actual electrolysis is concerned, the recent scientific work of Haber [1] is of interest; he has been able to explain the conditions necessary for satisfactory working. One of the most important factors in the expense of manufacture is the cost of purifying the bauxite, which is an hydrated oxide of aluminium, containing always a considerable percentage of silica, iron oxide, and titanic acid. The process most generally in use at the present time is that of Bayer, which is purely chemical in nature.

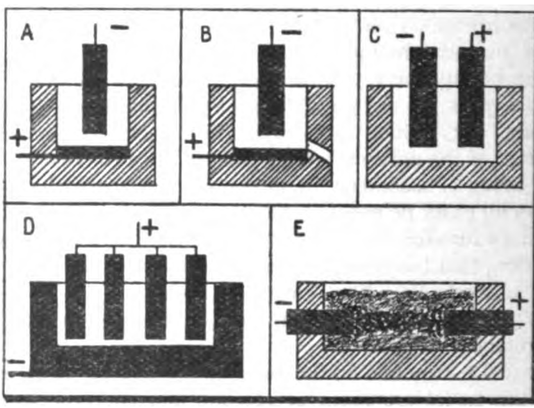

FIG. 13.—Principal Types of Electric Furnaces.

A. Represents the ordinary pot furnace in which the current passes between a movable carbon electrode, and a carbon or other plate forming the base of the furnace.

B. Is an example of a tapping furnace, being otherwise very similar to A.

C. In this case the furnace proper is formed of insulating material (generally lined with the unacted-on mixture), the current passing between the two carbons.

D. Represents electrolytic furnaces such as are used for aluminium, zinc, &c., the current passes from one or several carbon electrodes forming the positive electrode to the negative pole, which is formed by the lining of the furnace.

E. Resistance furnace: most frequently provided with a core through which the current is passed, and thus the surrounding material is heated.

All the types except D are suitable either for alternating or direct current, the former being most frequently in use.

A method recently invented by Hall proposes the purification of the bauxite in an electric arc furnace of type A, Fig. 13, by heating the mineral in contact with sufficient carbon or other reducing material to remove the impurities, and leave the oxide in a fused state. The oxide after cooling is removed, and is a grey friable material easily soluble in the cryolite; it is considered that this may considerably cheapen the manufacture. The total output of aluminium can be gleaned only from very insufficient data, the companies refusing to give

[1] Haber and Geipert, *Zeitschr. für Electrochemie*, vol. 8, pp. 1, 26, 607 (1902).

official statistics; however, it is said to have been approximately 7,500 tons for 1901. The yield usually obtained is about 1 lb. of aluminium per 12 H.P. hours.

SODIUM.—This metal has for long been produced by the Castner process,[1] which is carried out at Runcorn, Niagara, in Germany and France, and consists in electrolysing fused caustic soda; the metal being lighter than the electrolyte rises to the top and is removed from time to time. The construction of the cell is of some interest, since by an ingenious arrangement of the anode and cathode a high current efficiency is obtained. The important consideration seems to be the exact regulation of the temperature, since at already 20° above the melting point the recombination of the separating sodium is said to be so active that no metal comes to the surface. Several descriptions of the technical process have been given, and the current efficiency stated to be 70–90 per cent. At Niagara some 120 cells, each taking 1,200 amperes at 5 volts, are in use.

A careful study of this electrolysis has recently been made by Le Blanc and Brode,[2] who prove that the primary products are sodium at the cathode and oxygen and water at the anode; they do not seem, however, to have carried out many experiments at the lower temperatures, but state that the water remaining in the fused substance reacts with the sodium produced at the cathode, thus lowering the efficiency to 50 per cent., which is considerably below that quoted for the technical process. Sodium has also been produced by the Darling[3] process, in which the fused nitrate is electrolysed in cast-iron vessels provided with a thick diaphragm of magnesia and cement, with the production of nitric acid at the anode, and metallic sodium at the cathode. Each cell takes 400 amperes, but the voltage is as high as 15 volts.

CAUSTIC SODA.—The problem of the electrolytic production of caustic alkalies and chlorine has for long been an important one, and has already met with a large amount of success, the Griesheim-Elektron, Castner-Kellner, and Hargreaves-Bird processes being amongst those which are worked on a large scale; all these, however, deal with aqueous solutions, and we are therefore not concerned with them here. The direct treatment of fused salt offers considerable theoretical advantage, and several processes have been proposed, and amongst these we may mention the methods of Vautin, Hulin, and Acker,[4] all of which employ fused lead as a cathode to the sodium. The latter has been working since December, 1900, at Niagara Falls, with very satisfactory results, using some 3,250 H.P. The entire success depends on rapidly removing the sodium alloy as formed, since its diffusion into

[1] *English Patent* No. 13,356 (1890); *Electro-Chemical Industry*, vol. 1, p. 15 (1902); *Journal Soc. Chem. Industry*, p. 777 (1891); Rathenau and Suter, *German Patent* No. 96,672 (1896); R. Pauli, *Chemische Zeitschrift*, vol. 1, p. 497 (1902).

[2] Le Blanc and Brode, *Zeitschr. für Elektrochemie*, vol. 8, pp. 697–707, 717–729 (1902).

[3] Darling, *Journ. Franklin Instit.*, vol. 153, pp. 65–67 (1902).

[4] Vautin, *Eng. Patent* 13,568, 1893; *Journ. Soc. Chem. Industry*, vol. 13, p. 448 (1894). Townsend, *Electrical World and Eng.*, vol. 39, pp. 585–587 (1902). Acker, *Trans. Amer. Electro-chemical Soc.*, vol. 1, p. 165 (1902).

the mass of lead takes place only very slowly, and the richer alloys are unstable in presence of the fused salt. Acker has produced this rapid circulation by employing a steam injector, which causes the lead to flow rapidly past the anodes, and at the same time oxidises out the sodium, producing directly anhydrous fused NaOH. The temperature at which the steam and lead alloy come in contact is already high, but is still further raised by the heat of combination of the sodium, and thus of course any excess of steam passes off without combining with the caustic soda. The circulation is so good that the lead alloy in the cell does not average above 4 per cent. Na. The chlorine is drawn

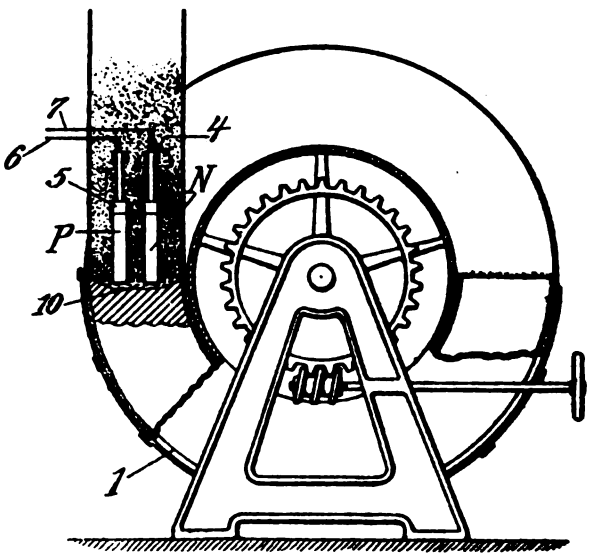

FIG. 14.—The Horry Calcium Carbide Furnace.

This is essentially a furnace of type C, Fig. 13, the current passing between two vertical carbons P and N, which are fixed. On the other hand, the enclosure containing the material is automatically lowered so soon as the mixture in the neighbourhood of the electrodes has been transformed into molten carbide. This is effected by constructing the furnace in the form of a drum which rotates very slowly, heating is produced in a space formed by the wide flanges of the drum, the drum itself, and plates bolted on to the periphery; these metal parts are sufficiently protected by the unacted-on material. Diametrically opposite the heating zone, at the back of the furnace the plates are unbolted and the carbide removed. This furnace combines several of the advantages of the continuous and discontinuous types; it is continuous in the true sense of the word since the power is never turned off, on the other hand the molten carbide is not removed until it has cooled down and imparted a considerable amount of its heat to the surrounding material. The speed of rotation of the wheel is regulated in such a manner as to keep the current approximately constant.

out by a fan, and used for producing bleaching powder. The cells, which are arranged in pairs, one on each side of a central flue, are cast-iron tanks with linings above the level of the fused lead.

Here again the inherent difficulties of furnace-linings are surmounted by leaving a sufficient coating of unfused material which protects the

walls. A central channel is provided below the actual electrolytic vat, by which the lead which has been freed from its sodium is returned.

The distance between the fused lead cathode and the carbon anode is very small, and thus the internal resistance is kept low. The anodes in each cell are four in number, and are formed of graphite 7½ × 14 inches; they carry 2,000 amperes each, the voltage being 7. Forty-five cells are run in series. The anhydrous caustic formed runs over an iron lip into a receptacle placed to receive it. The current efficiency averages 94 per cent.

ZINC.—Various processes have been proposed, and some are in actual use. The recently perfected "Phœnix" process of Swinburne and Ashcroft enables zinc to be produced by the electrolysis of the fused chloride, and is of particular interest on account of its application to the treatment of complex Broken Hill ores.[1]

MANGANESE.[2]—In some respects very similar to the aluminium process is that recently worked out by Simon and Gin for the production of manganese. A bath of fused calcium fluoride is employed in which the oxide is dissolved and submitted to electrolysis, carbon being added to assist in the reduction. The advantage of complete regulation of the temperature is in this case of great importance, since manganese is already easily volatile at temperatures only slightly above its melting-point.

PHOSPHORUS.[3]—Already in 1888 Readman and Parker perfected a satisfactory commercial process for the manufacture of phosphorus in the electric furnace. This method was tried on a large scale at the works of the Electric Construction Company at Wolverhampton, and seems since then to have been used by Messrs. Albright and Wilson at Oldbury. This firm is also closely connected with the Oldbury Chemical Company, who operate a plant at Niagara Falls. The method employed is very simple, the phosphate-mineral in a finely powdered state being mixed with carbon and sand, and heated in a closed electric furnace, the phosphorus distilling off and being collected under water. Other electric furnace methods are in use at Griesheim and in France, and there is no doubt that for long the advantages of the direct-furnace treatment have been fully made use of, although few details have been allowed to escape.

NITRIC ACID.[4]—The fascination of the direct synthesis of an important chemical compound has for long directed attention to the production of nitric acid from the nitrogen and oxygen of the air. The research of Rayleigh and Ramsey on the isolation of argon, followed by the im-

[1] Ashcroft, *Inst. Mining and Metallurgy*, 1901; *Electro-Chemist and Metallurgist*, pp. 244–249, 269–271 (1901).

[2] Simon, *Engl. Patent* No. 17,190 of 1900; Gin, *La fabrication électrique du Ferro-Manganèse en France, procédé Simon*, Paris, 1901.

[3] Readman, *Engl. Patent* 14,962 of 1888; Parker and Robinson, *Engl. Patent* 17,719 of 1888; Readman, *Journ. Soc. Chem. Industry*, vol. 10, p. 445 (1891); *Thorpe's Dict. of Chemistry*, vol. 3, p. 192: Machalske, *Electrical World and Engineer*, vol. 37, p. 360 (1901); Irvine, *Electrical World and Engineer*, vol. 38, p. 374 (1902).

[4] McDougall and Howles, *Manch. Lit. and Phil.*, vol. 44, part 4, No. 13, pp. 1–19 (1900); Bradley, *Electrical World and Engineer*, vol. 40, p. 159 (1902); Rayleigh, *Journ. Chemical Society*, vol. 71, p. 181 (1897).

portant British Association address delivered by Crookes in 1898, helped to emphasise the importance of this subject. The careful work carried out by McDougall and Howles, which has not received the attention it deserves, was more particularly directed to a study of the efficiency of this process. By employing an alternating high-tension arc in air they succeeded, by a study of the necessary conditions, in obtaining a yield of 300 gms. HNO_3 per 12 H.P. hours, in this way combining 51 per cent. of the air passed through their apparatus,

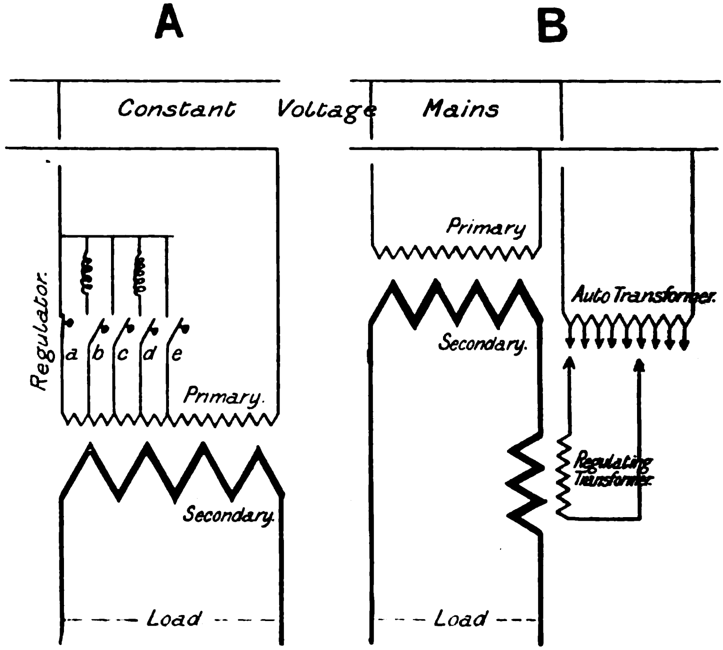

FIG. 15.—Regulating Transformers for Electro-chemical Work.

A. Shows the first method which consists in altering the transforming ratio by cutting out a certain number of the primary turns. As connected the E.M.F. of the secondary circuit would be a maximum, to reduce it the switch *B* is closed and *A* is opened, C closed and *B* in turn opened, each successive operation diminishing the E.M.F. by a fixed amount, the regulation being thus carried out without breaking the current.

B. Represents a second method which consists in using a boosting transformer. The current of the primary of the booster is adjusted according to the volts required in the secondary. In the diagram this is achieved by connecting it with a certain number of turns of an auto-transformer placed across the mains.

whilst with a mixture of two volumes oxygen to one volume of nitrogen the yield rose to 590 gms. per 12 H.P. hours. In most of their experiments they used a transformer giving 8,000 volts. The work of Bradley and Lovejoy at Niagara has given more favourable results from an economical point of view. A considerable amount of preliminary work pointed out the advantage of the direct current, and the apparatus now working employs a 10,000-volt continuous-current dynamo. As

will be seen in Fig. 17, the negative pole of the dynamo is connected to an axis carrying six radial arms, the positive poles being placed round the periphery of an iron cylinder which forms the combustion chamber. A choking coil is placed in each circuit. The actual apparatus comprises twenty-three such stars fixed one above the other on the same vertical axis, which revolves at the rate of 500 revolutions per minute, forming and breaking 414,000 arcs per minute. The chief function of this rotation is the rapid cooling down of the products of the combustion, which, if allowed to remain under the heating influence of the arc, would dissociate. For the same reason a rapid flow of air has been adopted, so that the issuing gases only contain about 2 to 3 per cent. oxides of nitrogen. The yield obtained is 1 lb. nitric acid per 7 H.P. hours. The process is considered to have already passed the experimental stage, and at the present time steps are being taken to start it on a commercial scale.

FUSED ALUMINA.—We have already mentioned the method of Hall for purifying bauxite by fusion in the electric furnace in presence of carbon or other reducing material. Our present consideration, however, is the manufacture of an artificial abraisive by the direct treatment of bauxite. The only method, so far as is known, in actual operation is that patented by Jacobs which is now being employed at Niagara Falls, by the Norton Emery Wheel Company, for long known as important manufacturers of abraisive articles of natural corundum. It has been found that the electric furnace product possesses advantages over the best grades of natural material. The bauxite is first thoroughly calcined in ordinary furnaces, and is then heated to fusion in an arc furnace of type B, Fig. 13. The plant at present in use, which is about to be further extended, employs some 500 H.P. and produces daily from 4–5 tons of fused alumina, called "alundum" to distinguish it from corundum. The material exhibits at times considerable crystalline formations.[1]

BARYTA.—This material is being prepared at Niagara by the United Barium Company, Barytes ($BaSO_4$), together with some reducing material, being treated in the electric furnace. The reaction which first takes place is as follows:—

$$4BaSO_4 + 4C = BaS + 3BaSO_4 + 4CO.$$

The Barium sulphide then reacting with the sulphate to give anhydrous baryta.

$$BaS + 3BaSO_4 = 4BaO + 4SO_2$$

In practice 500 k.w. tapping furnaces are in use, which yield a mixture of oxide and sulphide. These are easily separated in aqueous solution yielding a very good quality barium hydrate. The sulphide can afterwards be carbonated or otherwise worked up.[2]

CARBON BISULPHIDE.—As we have pointed out previously, the electric

[1] Jacobs, *U. S. Patent*; Gintl, *Zeitschr. für angew. Chemie*, p. 1173 (1901); Hasslacher, *German Patent* 85,021 of 1896.

[2] Jacobs, *Journ. Soc. Chem. Ind.*, vol. 21, p. 391; Limb, *Eng. Patent* No. 7,282 (1899).

furnace is usually employed for producing chemical reactions which require temperatures otherwise unattainable. In the manufacture of carbon bisulphide the advantage of electric heating lies, however, in the fact that a more perfect control of the furnace temperature can be thus attained, the temperature required being very low. The method invented by E. R. Taylor for producing this substance consists in the direct treatment in the electric furnace of charcoal and sulphur. The manufacture has been carried out for some time at Penn Yan, New York, the daily output being some 10,000 lbs. The furnaces are decidedly the largest at present in use in any electro-chemical works, being some 40 feet high by 16 feet diameter. The sulphur is fed in continuously so as to rise from below the electrodes where it comes in contact with coke, which forms a resistance bridge between the carbons, in this way becoming vapourised and brought into contact with the charcoal which fills the rest of the tower; combination takes

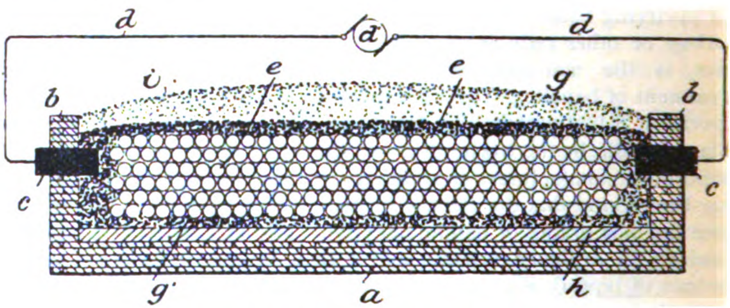

FIG. 16.—Acheson Graphite Furnace.

This shows the furnace fitted for graphitising electrodes; as will be seen, the current passes through the charge, which itself forms the heating resistance. The carborundum furnaces are of a similar type, but on account of the high resistance of the material are considerably shorter, and are provided with a central core of coke. Each furnace absorbs 1,000 H.P. and is run for twenty-four hours. It is capable of graphitising 3½ tons of carbon electrodes or 6 tons of anthracite.

place, and the CS_2 produced is led off and condensed. By the application of this process a very considerable cheapening in the cost of production has been effected.

STEEL.—The application of the electric furnace to the melting of steel, which was one of the first problems worked upon the Siemens, has been revived during the last few years in many different forms. The proposals, which not only include the manufacture of steel from pig-iron, but also the direct production by electric smelting of the ore, have led to the design of many special types of furnaces.

De Laval[1] invented an ingenious furnace for making steel in which the metal was melted by bringing it in contact with fused oxide of iron heated electrically by resistance. This method is reported to have been tried on a large scale at Trollhättan in Sweden, but to have been a financial failure.

[1] *Jahrbuch der Elektrochemie*, vol. 1, p. 123 (1894).

Stassano's[1] furnace was in design somewhat similar to the blast furnace, the necessary heat being produced by the electric arc. A company was formed to work this process in Italy, but is said to have since ceased operations. One ton of metal was produced per 3,000 H.P. hours.

Harmet,[2] of the "Fonderies, Forges et Acieries," at St. Etienne, has worked out a method for treating iron ore in three stages, the carbon monoxide evolved by the reduction being partly used to heat the raw materials, whilst the reduced metal is transformed into steel in a separate electric furnace. Works are being erected at the present time for making use of this process.

Ruthenberg[3] has worked more particularly on the magnetic concentration of low grade ores and their subsequent fritting in the electric furnace.

Conley[4] proposes the reduction of iron ores by passing them between two high resistance plates which are kept heated by the passage of a current; the metal falls into a hearth, which is also electrically heated.

Gin has brought forward a method of heating mixtures of iron oxide and sulphide ores, with production of sulphuric acid and ferro-silicon as by-products.

Keller[5] has designed a furnace which is being employed in works at Kerrousse (Morbihan).

Processes of electric melting by induced currents have been proposed by Benedicks[6] in Sweden and Schneider[7] in France; in both cases the metal contained in an annular crucible forms the electric conductor surrounding an iron ring, in which rapid alterations in magnetic flux are produced. Benedicks' contrivance is similar in principle to a welding transformer, the entire secondary circuit of which is formed by the molten metal. This process is in actual work at Gysinge, where 300 H.P. are employed, and 1,500 tons steel can be produced per annum. Schneider, on the other hand, produces an alternating magnetic field by the rotation of a shuttle wound armature. The outlook of these inventions can only be regarded as immediately hopeful in localities in which water power is available at an exceptionally low cost; the value of any economically successful process, however, can hardly be over-estimated.

GLASS.—The accuracy with which temperatures produced by electric methods can be adjusted has led to several proposals for the application of the electric furnace to the glass industry, where, as is known,

[1] *Jahrbuch der Elektrochemie*, vol. 6, p. 320 (1899); *Zeitschr. für Elektrochemie*, vol. 8, pp. 61, 852 (1902); *Journ. Soc. Chem. Industry*, vol. 20, p. 816 (1902).

[2] Harmet, *Étude sur l'Electrometallurgie du Fer*, I. and II. Cf. also *Electrochemist and Metallurgist*, vol. 9, p. 18 (1902); *Zeitschr. für Eletrochemie*, vol. 8, p. 852 (1902).

[3] Ruthenberg, *Eng. Patent* 13,867, 1902; *Electrochemist and Metallurgist*, vol. 2, p. 12 (1902); *Jahrb. der Elektrochemie*, vol. 1, p. 516 (1902).

[4] Conley, *Electrochemist and Metallurgist*, vol. 2, p. 16 (1902).

[5] Bertholus, *Notice sur la Fabrication des aciers au Four Electrique*, Paris, 1902.

[6] Benedicks, *Eng. Patent* No. 18,921 of 1900

[7] Schneider, *Eng. Patent* No. 7,338 of 1901.

the temperature regulation is one of the most important factors. Trials are being made on a commercial scale at Plettenberg (Westphalia).[1] With regard to quartz, since the temperature required is very high, the electric is the only method available for fusing this material in bulk. Considerable difficulties will have to be overcome, however, before this most valuable substance can be manufactured on a commercial scale.

CONCLUSION.—Although the above account is by no means exhaustive, we feel that we have already reached, if not exceeded, the limits of space which are usually allotted for a paper of this kind. In our brief review of the subject it has in most cases only been possible to describe summarily for each product one particular method of manufacture, which, however, we have tried to choose as being one worked on a large commercial scale, but it must be borne in mind that by so doing

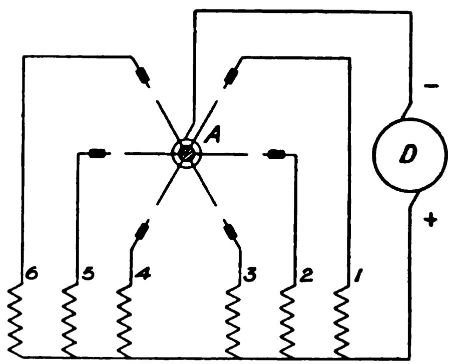

FIG. 17.—Diagram of Bradley Nitric Acid Plant Connections.

The dynamo D giving 10,000 volts has its negative pole connected with the revolving axis A, whilst the positive is connected to all the separate stationary electrodes through the choking coils 1, 2, 3, &c.

Twenty-three similar sets of stars are superimposed on the same axis. The positive electrodes are vertically one above the other; the negative electrodes, however, are displaced about 2½ degrees, the arcs being thus drawn out in rapid succession.

it has not been our intention to in any way detract from the value of other methods, which, although less generally used, may frequently possess advantages over those we have mentioned.

Perhaps, however, before closing we may be allowed to say a few words with regard to the theoretical efficiency of electric furnaces, about which so much has of late been written. Calculations have been made referring to each of the manufactures, but the reliability of these varies largely from case to case. When dealing with the highest temperatures very few data are available with regard to the specific heat, latent heat, or heat of combination of the various materials employed. It was previously customary to assume a constant specific heat, but

[1] *Zeitschr. für Elektrochemie*, vol. 8, pp. 419–421 (1902); Völker, *Eng. Patent* No. 23,903 (1900).

more recently this has been shown to be untenable, and most of the modern calculations consider the specific heat as a linear function of the temperature, relying for their values for the higher temperatures on a very considerable extrapolation. The actual specific heats have been experimentally determined for a limited number of substances up to some 1,500° C., and it is hardly necessary to insist on how considerable an error can be caused by boldly applying these values to twice the absolute temperature. In addition it must be remembered that the second factor in the calculation, the actual temperature of a furnace, is in most cases practically unknown.

The temperature of volatilisation of carbon is usually taken as 3,400° C., but this is no measure of the temperature of the arc flame, which may be considerably higher. On the other hand, the average temperature of the furnace is always considerably below that of the volatilisation point of carbon.

The consequence of this rash way of dealing with the subject is that the estimates of the theoretical amount of heat required differ by nearly 100 per cent., as has been shown by Kershaw in the case of calcium carbide.[1]

With regard to those of the resistance furnaces in which the temperature is comparatively low, more accurate data can be obtained, and finally, in the electrolysis of fused salts, the calculations give a much more trustworthy result, depending as they do largely upon the electro-chemical equivalents, which are known with some accuracy.

The determination of the total loss of heat by radiation from an electric furnace provides, however, valuable information on one of the important factors in the efficiency, but the final criterion in all commercial work must necessarily be the number of tons yield per H.P. year. In describing the various methods it has been of great advantage to have means by which personal experience of the process could be obtained by direct experiment. For this we are indebted to the foresight of Professor Arthur Schuster, F.R.S., who, thanks to the munificence of Mr. Ivan Levinstein, was able to make ample provision for experimental electro-chemistry in the building in which we are now assembled.

[1] Kershaw, *Electrician*, vol. 46, pp. 164, 245, 267 (1900).

Institution of Electrical Engineers.

FORM OF MODEL GENERAL CONDITIONS

RECOMMENDED

FOR USE IN CONNECTION WITH CONTRACTS FOR PLANT, MAINS, AND APPARATUS FOR ELECTRICITY WORKS,

As drafted by a Committee appointed for the purpose, and presented to the Council for adoption as the Model General Conditions recommended by the Institution of Electrical Engineers.

A Committee was appointed by the Council on the 20th of December, 1900, and met first on January 7th, 1901 ; it was then arranged:—

(1) To send copies of the original Draft, for the purpose of eliciting criticisms and suggestions, to the Electrical Plant Manufacturers' Association, to the Cable Manufacturers' Association, and to the Municipal Electrical Association, as well as to certain engineers and manufacturers, and

(2) To consider such replies as should be received when examining the draft Conditions in detail.

At the request of the Committee, the three Associations above named, and also the Engineering Employers' Federation, appointed delegates to confer with the Committee, and at a subsequent Council Meeting these delegates were formally added to the Committee, which was much strengthened and greatly assisted by their co-operation.

The meetings of the Committee were well attended, and the draft General Conditions were considered individually in great detail, the views of all parties being carefully studied, and, as far as possible, harmonised. The General Conditions, with the emendations and additions made in the first survey, were re-examined in detail, and were then submitted to Counsel. They were then discussed at an Ordinary General Meeting of the Institution, and were then reconsidered by the Committee and again submitted to Counsel, and laid before the Council of the Institution. The form of General Conditions hereto subjoined is that agreed to.

FORM

OF

MODEL GENERAL CONDITIONS

FOR

ELECTRICITY WORKS CONTRACTS.

LIST OF GENERAL CONDITIONS.

DEFINITION OF TERMS—

1.—In construing these Conditions and the annexed Specification, the following words shall have the meanings herein assigned to them :—

* Here fill in the full title of the Purchasers.

The "Purchasers" shall mean *

and shall include their legal personal representatives, successors and assigns.

The "Contractor" shall mean the Tenderer whose tender shall under these conditions be accepted by the Purchasers, and shall include his legal personal representatives and assigns.

† Here fill in the name of the Engineer.

The "Engineer" shall mean Mr. †   , or other the Engineer for the time being, or from time to time duly authorised and appointed in writing by the Purchasers to superintend the construction and erection of the work or works the subject of the Contract.

"Work" or "Works" shall mean and include work to be done and plant and materials to be provided by the Contractor under the Contract, and where appropriate according to the context "Work" or "Works" as used in these Conditions shall include or denote plant and materials.

The "Contract" shall mean the agreement to be entered into between the Contractor and the Purchaser under Clause 10 of these Conditions, and shall include the General Conditions, Specification, Drawings, Form of Tender and Schedule of Prices.

The "Specification" shall mean the specification annexed to these General Conditions.

The "Site" shall mean the Site of the Electricity Works, situate in

[*Here give full description of locality.*]

and any other place in the said where work is to be executed under the Contract.

"Writing" shall mean any written, typed or printed statement under or over signature or seal as the case may be.

Words importing the singular shall also import the plural and *vice versâ*.

DRAWINGS ISSUED WITH SPECIFICATION—

2.—The Drawings issued with the Specification are enumerated under the different Sections to which they refer. They will be issued only to Tenderers under these Sections.

FOUNDATIONS AND BUILDERS' WORK—

3.—Unless otherwise specified, the necessary Foundations and builders' work generally will be provided by the Purchasers.

USE OF CRANE—

4.—Each Contractor for plant to be erected in the Engine House will be permitted for the purposes of the Contract to use, free of charge, but at his own risk, and entirely under the directions of the Engineer, the -ton overhead crane in the Engine House, but each Contractor will be required to leave the same in as good a condition as he finds it, fair wear and tear excepted, and he shall not so use it as to hinder or interfere with the use thereof by the Purchasers or any other Contractor.

SITE—

5.—Proper access will be provided by the Purchasers to the place where the work is to be executed.

There will be (*or* will not be) a Railway siding of feet gauge on to the site.‡

‡ Full information as to the Site and point or points of access thereto should be set forth by the Engineer in this Clause or in some other writing.

TENDERER'S SPECIFICATION—

6.—The Tenderer is required to fill in the details of his Tender in the spaces provided for the purpose at the end of each Section of the Specification. Such statement will be accepted in lieu of a detailed specification, but the tenderer is at liberty to add any

details that he may deem desirable, and in the event of his doing so shall print or type the same and annex the added matter to the Specification returned by him, but such additional details shall not be binding on the Purchasers unless they are approved by them and incorporated in the contract.

DRAWINGS TO ACCOMPANY TENDER—

7.—The Tenderer must submit with his Tender the drawings enumerated in the section for which he is tendering, drawn to as large a scale as is convenient.

Detailed drawings are not required to be submitted with the Tender; but if the Tenderer wishes to call special attention to any detail of construction, he may submit a drawing of the same with his Tender. All drawings and samples submitted by unsuccessful Tenderers shall be returned within fourteen days of the date of the adjudication of the Purchasers upon the Tenders.

Note.—It is advisable that the advertisement inviting Tenders should notify a suitable place where the General Conditions, Specification and Drawings may be inspected, and should give such particulars of the class of plant and apparatus required under each section as will enable Contracting firms to decide, without obtaining the Specification, whether they are able to tender, and should also state the amount of the Deposit to be paid for the General Conditions, Specification and Drawings.

TENDERS—

8.—The copy of the Specification herewith supplied to each Tenderer must be filled up, returned intact, together with the General Conditions and Drawings, sealed and marked "Tender for Electricity Works," addressed to

and must be received by him before p.m. on

The Purchasers reserve to themselves the right of accepting a separate Tender or separate Tenders for any one or more of the Sections of the Specification, but not for part of a section.

The Purchasers do not bind themselves to accept the lowest or any Tender, nor will they be responsible for, or pay for, expenses or losses which may be incurred by any Tenderer in the preparation of his Tender, except as provided by Condition 10.

The sum deposited by the Tenderer on application for the Specification will be refunded to him within fourteen days of the date of the adjudication upon the Tenders, unless in any case the Purchasers on the advice of the Engineer shall determine that the Tender was not made in good faith, in which case the deposit shall be forfeited. Extra copies of the Specification and General Conditions may be supplied by the Engineer to Tenderers on payment of (*five shillings*) per set, and extra copies of the Drawings at a reasonable price. The Engineer shall decide whether a Tenderer should or should not be so supplied.

CONTRACTOR TO INFORM HIMSELF FULLY—

9.—If the Contractor shall have any doubt as to the meaning of any portion of these General Conditions or of the Specification

he shall, before signing the Contract, set forth the particulars thereof, and submit them to the Engineer in writing, in order that such doubt may be removed.

CONTRACT AND BOND—

10.—The Contractor shall enter into a sealed Agreement for the proper fulfilment of the Contract, and provide two Sureties, or Grantors of an Insurance or Guarantee Policy, whose names shall be set out in the Tender, and be subject to the approval of the Purchasers, and who shall execute a joint and several bond or grant an Insurance or Guarantee Policy to the extent of 10 per cent. of the value of the Contract, by way of suretyship for the due and faithful performance of the Contract, as defined by these conditions, such suretyship to be binding notwithstanding any variations, alterations, directions, or extensions of time to be made, given, conceded, or agreed under these conditions.

The required agreement and instrument of suretyship shall be prepared or approved by or for the Purchasers and they shall forward the same to the Contractor not less than thirty days from the date of acceptance of his Tender.

In case the Contract and Bond or Security shall not be executed by the Contractor and his Sureties, Insurers, or Guarantors respectively within thirty days after the same shall have been presented to the Contractor for that purpose, the Purchasers shall not, unless they think fit, be bound by their acceptance of the Tender, or by the Contract, but the same shall, at the option of the Purchasers, be absolutely void, and if the Purchasers, by notice in writing to the intending Contractor, declare the same to be void, the Purchasers shall not be liable to or for any claim or demand from the Contractor, in respect of work then already done or materials furnished, or in respect of any other matter or thing whatsoever.

In case the Contract shall not be executed by the Purchasers within thirty days after receiving the executed portion from the Contractor, the Tenderer shall not, unless he thinks fit, be bound by his Tender, but the same shall, at his option, be absolutely void, and if the Tenderer, having duly complied with these conditions, shall, by notice in writing to the Purchasers, declare the same to be void, the Tenderer shall not be liable to or for any claim or demand from the Purchasers, but the accepted Tenderer shall be entitled to be repaid the proper expenses of his Tender, together with any sum or sums in respect of work then already done or materials furnished, at the request in writing of the Purchasers.

The expenses of completing and stamping the Contract and Bond or Insurance or Guarantee Policy shall be paid by the Purchasers, and the Contractor shall be furnished with an executed counterpart of the Contract.

CONTRACT DRAWINGS—

11.—The Contractor shall submit, for the Engineer's approval, a preliminary set of the drawings set out under each Section of the Specification, by the dates therein indicated.

Within fourteen days of the receipt of the preliminary set of drawings the Engineer must signify his approval or otherwise of the same.

Within fourteen days of the notification by the Engineer to the Contractor of his approval of the preliminary set of drawings, two additional sets, in ink on tracing cloth or ferrogallic prints mounted on cloth, of the drawings as approved shall be supplied to him by the Contractor and be signed by him and by the Contractor respectively and be thereafter deemed to be the "Contract Drawings."

These drawings when so signed shall become the property of the Purchasers and be deposited with the Engineer, and shall not be departed from in any way whatsoever except by the written order of the Engineer as hereinafter provided. During the execution of the works one of the sets of drawings shall be available for reference on the site.

In the event of the Contractor desiring to possess a signed set of drawings, he may submit three sets, and in this case the Engineer will sign the third set and return the same to the Contractor.

The Contractor shall supply from time to time such additional drawings of any details as the Engineer may deem necessary for the execution of the work, but the Contractor shall not be called upon to furnish drawings of constructional details further than those which in the opinion of the Engineer are required for the purposes of the Contract.

The Engineer shall have the right, at all reasonable times, to inspect, at the works of the Contractor, drawings of any portion of the work.

If the Contractor shall not submit the drawings within the time specified, or subsequently within seven days after the Purchasers or the Engineer shall in writing have required him so to do, and if the delay shall not have been occasioned by the Purchasers or the Engineer, or any other Contractor, or other reasonable cause, the Purchasers may notify in writing to the Contractor that they will not be bound by the Contract, and on such notification the Contract shall be avoided and the Purchasers shall not be liable to or for any claim or demand from the Contractor in respect of work then already done or material furnished, or in respect of any other matter or thing whatever.

Or, *alternatively*, the Purchasers may, at their option, maintain the Contract, and in such case the Contractor shall pay or allow to them in account all expenses incurred by such default.

DRAWINGS OF FOUNDATIONS—

12.—Where Foundations are necessary, the Contractor shall supply the Engineer with Drawings of the Foundations necessary for his Plant, such Foundations being provided by the Purchasers (see Clause 3). The Contractor shall insure, by means of templates, the correct position of the foundation bolts and other details.

DEFECTS IN CONTRACTOR'S DRAWINGS—

13.—The Contractor shall be responsible for any mistake that may arise from any defect in the drawings supplied by him, and for any costs, damages, or expenses which may be sustained or incurred by the Purchasers by or in consequence of any such mistake, unless such drawings shall have been approved and signed by the Engineer.

DRAWINGS OF COMPLETED WORKS—

14.—Within one month of the taking over of the plant under Clause 41, and of the receipt of a list from the Engineer of working drawings of such portions of the plant as may reasonably be required for the future use of those in charge of the Works, the Contractor shall supply the same at the cost of production.

SUB-LETTING OF CONTRACT—

15.—The Contractor shall not, without the consent in writing of the Engineer, assign his Contract, or any substantial part thereof, nor under-let the same or any substantial part thereof, nor make any sub-contract with any person or persons for the execution of any portion of the works other than for raw materials, for minor details, or for any part of the work of which the makers are named in the Contract.

APPROVED APPARATUS—

16.—In all cases where plant or apparatus of "approved" type or make is required by the terms of the specification, the Engineer's approval thereof in writing must be obtained before such plant or apparatus is constructed or ordered, provided that if the Contractor shall have submitted with his tender drawings of the apparatus which he has included in his tender or otherwise shall have described the same in detail, the Engineer shall not

have the right to demand other plant or apparatus of a greater value than that so drawn or described.

NOTICES—

17.—All notices to the Contractor for the purposes of the Contract and these General Conditions, shall be sufficiently authenticated if signed by the Purchasers or by the Engineer; all notices from the Purchasers to the Contractor, and from the Contractor to the Purchasers shall be served respectively upon them personally, or by letter addressed to the places of business respectively named in the Contract, and any notice by letter shall be deemed to have been duly served at the time when the letter containing the same would be delivered in the ordinary course of post, and in proving such service it shall be sufficient to prove that the notice was properly addressed and posted. Provided always that if the Contractors or the purchasers respectively shall, after the Contract shall have been entered into, change his or their place of business and shall notify such change to the other of them in writing, all future notices if sent by letter shall after the receipt of such notification be addressed to such new place of business.

PATENT RIGHTS—

18.—The Contractor shall fully indemnify the Purchasers against any action, claim or demand, costs, or expenses arising from or incurred by reason of any infringement or alleged infringement of letters patent, trade mark or name, copyright or other protected rights, in respect of any plant, work, material or thing, system or method of using, fixing, working or arrangement used or fixed or supplied by the Contractor, but such indemnification shall not be operative in respect of any system or method of use that may be specifically mentioned by the Specification. All payments and royalties payable in one sum or by instalments or otherwise shall be included by the Contractor in the prices named in his Tender, and shall be paid by him to those to whom they may be due or payable.

In the event of any claim being made or action brought against the Purchasers in respect of any such matters as aforesaid, the Contractor shall be immediately notified thereof, and he shall, with the assistance, if necessary, of the Purchasers, but at his sole expense, conduct all negotiations for the settlement of the same, or any litigation that may arise therefrom.

MANNER OF EXECUTION, QUALITY OF MATERIAL, ETC.—

19.—The plant is to be manufactured, constructed, provided, erected in position, and maintained in accordance with the Contract, in the best and most substantial and workmanlike manner, and, unless otherwise specified, with materials of the best and most approved qualities for their respective uses.

POWER TO VARY OR OMIT WORK—

20.—The Contractor shall not alter, in any way whatsoever, any of the work, except as directed in writing by the Engineer ; but the Engineer shall have full power from time to time during the execution of the Contract to alter, amend, omit, or otherwise vary any of the work, without in any way affecting or vitiating the Contract, and the Contractor shall carry out such alterations, amendments, omissions, variations, or directions, and be bound by the same conditions, as far as applicable, as though the said alterations, amendments, omissions, variations, or directions occurred in the Contract. The difference of cost, if any, occasioned by any such alterations, amendments, omissions, variations, or directions, shall be added to or deducted from the Contract Price as the case may require. The amount of such difference, if any, shall be ascertained and determined in accordance with the rates specified in the Schedules of Prices, so far as the same may be applicable, and where the rates are not contained in the said Schedules, or are not applicable, they shall be settled by the Engineer and Contractor jointly. But the Purchasers shall not become liable for the payment of any charge in respect of any such alterations, amendments, variations, or directions unless the instruction for the performance of the same shall have been given in writing by the Engineer, nor unless such instruction shall state that the matter thereof is to be the subject of an extra or varied charge, nor unless the particulars of his claim shall be set forth in writing by the Contractor, and furnished to the Purchasers within thirty days after the execution of the same; but subject to these conditions being duly complied with, the Purchasers shall be bound by such particulars unless they or the Engineer object thereto in writing within thirty days after delivery thereof.

In the event of the Engineer requiring to dispense with or add to any part of the plant or works to be done under this Contract such reasonable and proper notice shall be given to the Contractors as will enable them to make their arrangements accordingly.

Unless the Contractor shall otherwise agree in writing, the total sum of money set out in the Contract shall not be affected by such alterations, amendments, omissions, variations, or directions to the extent of more than 10 per cent. of the amount of the Contract. Provided always that in cases where goods or materials are already prepared, or any matter or patterns made or work done that require to be altered in respect thereof, a reasonable sum shall be allowed by the Engineer.

NEGLIGENCE—

21.—If the Contractor shall fail to execute the work with due diligence and expedition, or shall refuse or neglect to comply with

any orders given him in writing by the Engineer, or shall fail to execute any other matter stipulated in the Contract, or shall contravene the provisions of the Contract, the Purchasers shall, after seven days' notice to the Contractor, in writing, be at liberty to employ other workmen, and forthwith perform such work as the Contractor may have failed to do, or, if the Purchasers shall think fit, it shall be lawful for them to take the works wholly, or in part, out of the Contractor's hands and re-contract with any other person or persons, or provide any other materials, tools, tackle, or labour for the purpose of completing the works or any part thereof, and the Purchasers shall, without being responsible to the Contractor for fair wear and tear of the same, have the free use of all the materials, tools, tackle, or other things, the property of the Contractor, which may be on the site, for use at any time in connection with the work, to the exclusion of any right of the Contractor over the same.

If the cost of completing the works exceed the balance due to the Contractor, the said materials, tools, tackle, or other things may be sold by the Purchasers, and the proceeds applied towards the payment of such difference. Any outstanding balance existing after crediting the proceeds of such sale shall be paid by the Contractor on the certificate of the Engineer, but when all expenses, costs, and charges incurred in the completion of the work are paid by the Contractor, all such materials, tools, tackle, or other things shall be removed by the Contractor.

DEATH, BANKRUPTCY, ASSIGNMENT, AND SUB-CONTRACTING—

22.—The conditions and penalties in favour of the Purchasers contained in the last preceding condition may, subject as hereinafter provided, be enforced by the Purchasers if the Contractor die, go into liquidation, become bankrupt or insolvent, or have a receiving order made against him, or compound with his creditors, or propose any composition to his creditors for the settlement of his debts, or assign his Contract without the consent of the Purchasers, or if the Contract become vested in any other person, or if he commit any act of bankruptcy, or carry on his business under an Inspector or a Receiver for the benefit of his creditors, or permit any execution to be levied on his property, or if he subcontract for any portion of the work otherwise than as provided in Clause 15. Provided that the consent of the Purchasers to an assignment of the Contract shall not be unreasonably withheld. In the case of the death, liquidation, insolvency, or other disability or act as aforesaid of the Contractor, his executors or other representatives in law of his estate shall have the option of carrying out the Contract subject to the Executors providing such additional

surety as may be required by the Purchasers as will bring the amount of the surety up to the Contract value of the work for the time being remaining unexecuted.

INSPECTION AND TESTING AT MAKER'S WORKS—

23.—The Engineer, and his duly authorised representative, shall have at all reasonable times access to the Contractor's Works, and shall have the power at all reasonable times to inspect, examine, and test the materials and workmanship of the plant during its manufacture there ; and if part of the plant is being manufactured on other premises, the Contractor shall obtain for the Engineer and for his duly authorised representative permission to inspect as if the plant were manufactured on his own premises.

The Engineer shall, on giving fourteen days' notice in writing of his grounds of objection, have liberty to reject all or any materials, plant or workmanship, which in his opinion are not in accordance with the Contract, or are defective for any reason whatever, and such rejection shall be operative at the expiration of such notice, provided that, if notice of any such rejection, setting forth the reason for such rejection, be not sent to the Contractor within fourteen days after the grounds upon which such rejection is based have come to the knowledge of the Engineer, he shall not be entitled to reject the said materials, plant or workmanship on these grounds.

The Contractor shall give the Engineer not less than seven days' notice of any material being ready for testing, and unless otherwise arranged, the Engineer, or his representative, shall proceed to the Contractor's Works within three days of the date on which the material is notified as being ready ; failing which visit the Contractor may proceed with the tests, and, in the absence of the Engineer, the tests shall be taken as if they were made in his presence.

TESTING APPARATUS—

24.—In all cases where the Contract provides for tests, whether at the works of the Contractor or the sub-contractor or on the site, the Contractor, except where otherwise specified, shall provide, free of charge, such labour, materials, chemicals, coal, oil, waste, apparatus, and instruments as the Engineer may consider requisite from time to time, and as may reasonably be demanded, to efficiently test the Plant, material or workmanship, in accordance with the Contract, and shall at all times give facilities to the Engineer or to his authorised representative to accomplish such testing

The apparatus, instruments, unused material, and apparatus so provided by the Contractor shall remain the property of the Contractor.

In the case of Cable contracts, current for tests on site shall be supplied free to the Contractors at the pressure of the ordinary supply.

DELIVERY OF MATERIALS—

25.—No Plant or materials shall be forwarded until an intimation in writing shall have been given to the Contractor by the Engineer that the Purchasers are ready to take delivery.

If the Purchasers withhold the forwarding of instructions so as to prevent the Contractor giving delivery by the dates stipulated in the Contract, the Purchasers shall bear the cost of the storage and protection, including fire insurance, of the Plant and materials, and make payments therefor as if delivery had been given, provided that possession thereof and the property therein be duly secured to the Purchasers.

ACCESS TO SITE—

26.—In the execution of the work, no persons other than the Contractor, or his duly appointed Superintendent, sub-Contractors and Workmen, shall be allowed to do work on the site, except by the special permission, in writing, of the Engineer, but access to the works at all times shall be accorded to the Engineer and his representatives, and other officials or representatives of the Purchasers.

MATERIALS BROUGHT ON TO THE SITE—

27.—The Contractor shall provide all materials, labour, haulage power, tools, tackle, and plant of every description, necessary to execute and complete the works in an efficient and satisfactory manner. All such materials, plant, tools, and tackle (except as provided by Clause 24 with regard to instruments and apparatus for testing and empty drums and packing cases), brought to and delivered upon the site for the purpose of the work, shall, from the time of their being so brought, vest in and be the property of the Purchasers until the completion of the Contract, when the property in any surplus materials, and in the plant and tools, shall revert to the Contractor, unless there shall be due, owing to, or accruing, or to accrue, from the Contractor to the Purchasers, any money or moneys under, or in respect of or by reason of this Contract, in which case the Purchasers shall be at liberty to sell and dispose of such surplus materials, plant and tools as they shall think fit, and to apply the proceeds in or towards the satisfaction of such money or moneys so due, owing or accruing, or to accrue to them as aforesaid.

If application be made to the Engineer by the Contractor, he may at any time permit the removal of such machinery, plant, tools, and tackle as may not be required for the execution of work under this contract, or which may be required by the Contractor for uses elsewhere.

ENGINEER'S SUPERVISION—

28.—All the works are to be carried out under the direction, control, and to the entire satisfaction in every respect of the Engineer; but the Contractor shall be responsible for the accuracy of his work, and no plea as to the acts, order, or general supervision of the Engineer otherwise than instructions given by him in writing will be admitted in justification of any errors of construction or fixing.

ENGINEER'S DECISIONS—

29.—In respect of all matters which are left to the decision or certificate of the Engineer, the Engineer shall, if required so to do by the Contractor, give in writing a decision thereon, and his reasons for such decision, or if he shall withhold any certificate then his reasons for so doing. All decisions of the Engineer shall be subject to the right of arbitration reserved by these conditions.

CONTRACTOR'S SUPERINTENDENT AND WORKMEN—

30.—The Contractor shall constantly employ at least one competent Superintendent to superintend the erection of the plant and the carrying out of the works. The said Superintendent shall be present on the site during working hours, and shall be prepared to receive from time to time orders and instructions from the Engineer or his duly authorised representative.

The said Superintendent, if objected to by the Engineer, on account of incapacity, misconduct, or negligence, shall be removed by the Contractor, and the Contractor shall, after receiving formal objection in writing, forthwith replace him by another Superintendent, competent to fulfil his duties.

The Engineer shall be at liberty to object to any person employed by the Contractor in the execution of or otherwise about the works who shall, in his opinion, misconduct himself or be incompetent or negligent, and the Contractor shall forthwith remove the person so objected to, and if necessary replace him by a satisfactory person who shall be the servant of and be remunerated by the Contractor.

LIABILITY FOR ACCIDENTS AND DAMAGE—

31.—The Contractor shall properly cover up and protect such of the work as may be liable to sustain injury by exposure. He shall also take every necessary, proper, timely and useful precaution against accident or injury to the plant, and shall be and remain answerable and liable for all losses, damages or injury which, during the progress of the work, and until it be taken over under Clause 41, may arise or be occasioned by the acts or omissions of the Contractor or his servants, but not for any subsequent consequential loss or damage, nor for any breakage or injury, wholly or partially caused by, or arising from, the acts of the Purchasers or others, or due to circumstances over which the Contractor has no control; and all such losses, damages, or injuries, if sustained by the Purchasers, shall be made good in the most complete and substantial manner by, and at the sole cost of the Contractor, and to the satisfaction of the Engineer, and the Contractor shall indemnify the Purchasers against all claims and demands in respect of such losses, damages, or injuries, if sustained by any other person or persons.

The Contractor shall likewise, until the Plant shall have been taken over under Clause 41, indemnify and save harmless the Purchasers against actions, suits, claims, demands, costs or expenses arising in connection with the Works under the Workmen's Compensation Act, 1897, and any other statute in force at the date of the Contract dealing with the question of the liability of employers for injuries sustained by employees.

In the event of any claim being made, or action brought against the Purchasers arising out of the matters referred to in this Clause, the Contractor shall be immediately notified thereof, and he shall, with the assistance if necessary of the Purchasers, but at his sole expense, conduct all negotiations for the settlement of the same, or any litigation that may arise therefrom. The Purchasers will, at the expense of the Contractor, afford all available assistance for any such purpose.

REPLACEMENT OF DEFECTIVE WORK OR MATERIALS—

32.—If during the progress of the work on site, the Engineer shall decide and notify in writing to the Contractor that the Contractor has executed any unsound or imperfect work, or has supplied any plant or materials of inferior quality to those specified, the Contractor shall at his own expense, within twenty-four hours of his receiving the notice, proceed to alter, re-construct, or remove such work, or supply fresh materials up to the standard of the Specification, and in case the Contractor shall fail to comply with such orders, the Purchasers may, without further notice, remove the work or materials complained of, and, at the cost of the Contractor, perform all such work or supply all such materials.

DEDUCTIONS FROM CONTRACT PRICE—

33.—All costs, damages, or expenses which the Purchasers may have paid, or be liable to pay, or which shall have become forfeited to the Purchasers as provided for by these Conditions and by the Specification, shall be paid by the Contractor to the Purchasers on the certificate of the Engineer, or if not so paid may be deducted from any moneys in their hands due or becoming due to the Contractor under the Contract, or recovered by action at law, or otherwise from the Contractor.

TERMS OF PAYMENT AND CERTIFICATES OF ENGINEER—

34.—The Contractor shall from time to time be entitled, upon the Certificates of the Engineer, to payments by the Purchasers by instalments in accordance with the following provisions:—

I.—As the Works progress, 80 per cent. upon the Contract value of the Work from time to time delivered or executed on the site to the satisfaction of the Engineer.

II.—The remaining 20 per cent. (referred to herein as retention money) in respect of each distinct Section or Part of a Section of the works as follows:—

(*a*) 10 per cent. at the expiration of one month after the Works shall have been taken over by the Purchasers under Clause 41 or alternatively, at the option of the Contractor, at the expiration of one month after the Works shall have been put into beneficial use by the Purchasers.

(*b*) 10 per cent. at the expiration of nine months after the first 10 per cent. becomes due under (*a*).

No part of the "Retention Money" will be payable at the time at which payment of the same ought otherwise to be made under the Contract, unless in the opinion of the Engineer the Works are then in good repair, and condition, and sound working order, fair wear and tear and accidental injury or damage by persons other than the Contractor's servants and not due to faulty workmanship or material, excepted. Provided, however, that where the defects are not of such importance as to affect the full beneficial use of the Works, the retention of the whole instalment shall not be insisted on, but the Purchasers shall be entitled to retain such less sum of money as, in the opinion of the Engineer, represents the damage to the Purchasers arising out of incomplete or defective details. Any sum retained under this clause will become due upon the adjustment of such details to the satisfaction of the Engineer.

Every application to the Engineer for a Certificate must be accompanied by a detailed claim (in duplicate) setting forth in the order of the Schedule of Prices, particulars of the work executed to the date of claim, and the Certificate shall be issued within 14 days of the application for same.

Not more than one Certificate shall be issued in any one month in respect of the same section.

The Engineer may by any Certificate make any correction or modification in any previous Certificate which shall have been issued by him, and payments shall be regulated and adjusted accordingly.

DUE DATES OF PAYMENTS—

35.—Payments shall be made by the Purchasers within thirty days from the date of each certificate of the Engineer.

In the event of the Purchasers failing to pay the Contractor any amount certified by the Engineer, within the specified period, and in accordance with the Contract the Contractor shall have the right, on giving 14 days' notice in writing to the Purchasers or the Engineer, to stop all operations, and the expenses incurred in resuming work shall be paid by the Purchasers to the Contractor as an extra over and above the amount payable under the Contract.

CERTIFICATES NOT TO AFFECT RIGHTS OF THE PURCHASERS OR CONTRACTOR—

36.—No certificate of the Engineer on account, nor any sum paid on account by the Purchasers, shall affect or prejudice the rights of the Purchasers against the Contractor, or relieve the Contractor of his obligations for the due performance of the Contract, or be interpreted as approval of the work done or of the materials supplied, and no certificate shall create liability in the Purchasers to pay for alterations, amendments, or variations not ordered in writing by the Engineer, or discharge the liabilities of the Contractor for the payment of damages, whether due, ascertained or certified, or not, or of any sum against the payment of which he is bound to indemnify the Purchasers, nor shall any such certificates affect or prejudice the rights of the Contractor against the Purchasers.

SUSPENSION OF WORKS—

37.—The Purchasers shall pay to the Contractor all reasonable expenses arising from suspension of Works by order in writing of the Purchasers or the Engineer unless such suspension be due to some default on the part of the Contractor.

DATES OF COMPLETION—

38.—The Works shall be completed on the site and ready for beneficial use or for testing by the date named under each Section, or by such other date (if any) as may be incorporated in the Contract.

Provided always that, if by reason of extra work, alterations in, or deviations from the Specification, directed in writing by the Engineer, or by reason of the suspension of the works under the direction of the Engineer, or of unusual inclemency of the weather, or by reason of civil commotion or general or local strikes, or lock-outs, or combinations of workmen, or in consequence of fire or of any unpreventable accident to or breakage of machinery in the manufacturers' premises or on the site, causing a delay in the supply of plant or materials to the Contractor, or by reason of the non-completion of a Section of the Contract executed by another Contractor, or by any act or default on the part of the Purchaser, or of other cause beyond the reasonable control of the Contractor, or by any delay on the part of the Purchaser to give forwarding instructions to the Contractor under Clause 25, the Contractor shall have been unduly delayed or impeded in the completion of the work, the Engineer shall, on the receipt of a written request from the Contractor, grant from time to time, and at any time or times, by writing under his hand, such extension of time, either prospectively or retrospectively, and assign such other day or days for the completion as to him may seem reasonable, without thereby prejudicing, or in any manner affecting, the validity of the Contract, and any and every such extension of time shall be deemed to be in full compensation and satisfaction for, and in respect of, any and every actual and probable loss sustained or which may be sustainable by the Contractor in the premises, and shall in like manner exonerate him from any claim or demand on the part of the Purchasers for, and in respect of, the delay occasioned by the cause or causes in respect of which any and every such extension of time shall have been made, but not further or otherwise, nor for, or in respect of, any delay continued beyond the time mentioned in such writing or writings respectively, provided that unless such request be made within two weeks after the expiry of the calendar month in which the delay existed no such extension of time shall be granted.

The Contractor shall not be called upon to commence any work which is of a nature requiring a building or structure for the reception or efficient installation thereof, and which building or structure is by the Contract to be provided by the Purchasers, unless and until such building or structure shall be in a condition sufficient for the reception or efficient installation of the Plant, and the Contract date of completion shall be extended *pari passu* with the delay in the providing of any such building or structure.

DAMAGES FOR DELAY IN COMPLETION—

39.—If the Contractor shall fail in the due performance of his Contract by and at the time fixed under the Contract, whether by way of extension or otherwise, the Engineer shall, in writing, certify the fact of such failure, and in such case the Contractor shall pay to the Purchasers, as and for agreed liquidated damages, the following amounts reckoned on the contract value of such portion only of the Works as cannot, in consequence of the delay, be used beneficially—

during the first four weeks between the appointed time and the actual time of completion, five shillings per £100 per week;

during the second four weeks, ten shillings per £100 per week;

during the third four weeks, fifteen shillings per £100 per week; and

during any subsequent week, twenty shillings per £100 per week.

PRELIMINARY TRIALS ON SITE—

40.—On the completion of the works on the site, the Contractor shall be at liberty, as far as convenient to the Purchasers, to make any preliminary trials that he may desire.

All expenses whatever of raising steam, or otherwise of or in connection with such preliminary trials, to which the Purchasers be put, shall be borne by the Contractor.

TESTS ON COMPLETION—

41.—On the completion of the works on the site, the Contractor, after giving the Engineer fourteen days' notice of his readiness to make the "tests on completion," shall test the operation thereof, either together or in sections, in the presence of the Engineer, and in all respects in accordance with and in manner provided by the Specification.

On the giving of such notice, the plant shall, for the purpose of the tests, be deemed to be complete, and no alterations or re-adjustments of the same shall be made within forty-eight hours before the time fixed for starting the tests, without the express permission of the Engineer in writing.

Should any alterations or re-adjustments be found necessary within forty-eight hours before the time fixed for starting the tests, the tests of the plant to which the alterations or readjustments are to be made may, at the sole option of the Engineer, be deferred for a period not exceeding fourteen days, and all reasonable expenses to which the Purchasers may be put by the deferring of the tests shall be borne by the Contractor,

The Contractor shall find and provide all necessary superintendence and labour for the purposes of the tests, and during the tests shall have the full working control of the plant.

If at the time agreed upon between the Contractor and the Engineer for the starting of the tests, the Engineer or his duly authorised representative shall fail to attend, the tests may proceed in his absence.

As soon as the tests have proved that the plant has completely fulfilled the Contract Conditions, the Engineer shall forthwith so certify in writing to both the Purchasers and the Contractor, and THEREUPON IT SHALL BE DEEMED THAT THE PURCHASERS HAVE TAKEN OVER THE PLANT.

If the works fail under the tests to fulfil the Contract Conditions, complete new tests shall, if required by the Engineer, or by the Contractor, be carried out upon the same terms and conditions, and upon payment to the Purchasers of all reasonable expenses to which they may be put by the repeated tests.

If the tests, proving that the works fulfil the Contract Conditions, be not made by the Contractor within one month after the date fixed under Clause 38 for the completion and the readiness of the works for beneficial use or for testing, and if, in the opinion of the Engineer, the tests are being unduly delayed, the Engineer may, in writing, call upon the Contractor under seven days' notice to make such tests, and on the expiry of such notice such tests shall forthwith be made by the Contractor.

If, after the expiry of the notice from the Engineer the Contractor neglects to make such tests, the Engineer may proceed to make such tests himself at the Contractor's risk and expense.

RIGHT OF USE—

42.—If the Contractor neglects to make the "tests on completion" by the dates stipulated under Clause 38, the Purchasers shall, nevertheless, have the right of using the works at their own expense for the supply of Electrical Energy or otherwise; but such use shall be at the Contractor's risk until he elects to make the "tests on completion" or until such tests prove that the plant fulfils the Contract Conditions. The Purchasers may, pending any Arbitration under the Contract, use any portion of the works reasonably capable of being used, but in such case the Contractor shall be entitled to be paid in respect of any work beneficially used, a sum equal to £5 per cent. per annum (according to the period of user) upon the amount withheld or deducted in respect of such work.

INTERFERENCE WITH TESTS—

43.—If any act of the Purchasers or of the Engineer, or the use of the work as above provided for, shall interfere with the Contractor carrying out the tests after the fourteen days' notice to be given by him to the Engineer, the payments to the Contractor shall be made as if final satisfactory "tests on completion" had taken place, but notwithstanding any such payments, the Contractor shall be liable to make, and shall make the said tests during the period provided for maintenance as and when required by the Engineer upon fourteen days' notice; and the obligations and liabilities of the Contractor shall be the same as if the tests had been made on the expiry of his fourteen days' notice.

The provisions of this condition as to payment shall apply in the event of such use, or any other act of the Purchasers, or of the Engineer, interfering with the remedying, by the Contractors, of any defects which may have appeared in the works.

REJECTION OF INEFFICIENT WORK—

44.—If the completed work or any portion thereof fails to pass the specified "tests on completion," or be defective in any way, the Engineer may reject such work or portion thereof, and the Purchasers shall then have the option of :—

(*a*) Permitting the Contractor to replace the defective work or,

(*b*) Themselves replacing the defective work by purchase from or contract with any other party or parties, or,

(*c*) Returning the defective Work and recovering the sum or sums paid or allowed on account of same.

In the event of (*a*), the substituted works shall be in all respects deemed to be subject to all the terms and conditions of the Contract.

In the event of (*b*), no further sum beyond that already paid to the Contractor in respect of the work in question shall be due or payable by the Purchasers to the Contractor in respect of such defective work, but the Contractor shall repay to the Purchasers any sum paid by them in respect of such work; and the Contractor shall also pay to the Purchasers any loss or damage to which they may be put by reason of the purchase or replacing of fresh work by them; it being agreed that if the Contractor shall fail to execute works in strict accordance with the Specification, it shall be lawful for the Purchasers, at their discretion, to obtain, without additional cost to them, the work in question from any other party or parties, or so to arrange for the execution of the works, as they may deem desirable, and that the Contractor

shall be liable for any loss suffered, or expenditure beyond the Contract prices incurred by the Purchasers in consequence of such failure.

In the event of (*c*), if the defective Work be required by the Purchasers for beneficial use, they shall be entitled to make use of the same for a reasonable time sufficient to enable them to obtain other work to replace it, the Contractors being allowed a reasonable sum for the use of the same.

MAINTENANCE—

45.—Until the final certificate shall have been issued the Contractor shall be responsible for any defects that may develop under normal and proper use arising from bad materials, design or workmanship in the Works. When called upon, in writing, by the Engineer to remedy such defects, the Contractor shall do so with due diligence, and unless such defects be remedied by the Contractor within a reasonable time, the Contractor shall be responsible for all losses and damages sustained by the Purchasers through such defects. If the defects be not remedied within a reasonable time, the Purchasers may proceed to do the work at the Contractor's risk and expense.

Until the final certificate shall have been issued, the Contractor shall have the right of entry by himself or his duly authorised representatives, at all reasonable working hours, upon all parts of the works for the purpose of inspecting the working and the records of the works and taking notes therefrom, and, if necessary, making any tests at reasonable times at his own risk and expense.

REQUIREMENTS OF LOCAL AUTHORITIES—

46.—The Contractor shall throughout the continuance of the Contract, and in respect of all matters arising in the performance thereof, promptly and effectually conform to all the requirements of any local or municipal authority in whose district the work may be executed, and provide for the safety and due convenience of the public.

ARBITRATION—

47.—If at any time any question, dispute or difference shall arise between the Purchasers or their Engineer, and the Contractor, upon or in relation to or in connection with the Contract, either party may forthwith give to the other notice in writing of the existence of such question, dispute or difference, and such question, dispute or difference shall be referred to the Arbitration of a person to be mutually agreed upon, or, failing agreement, to some person appointed by the President for the time being of the Institution of Electrical Engineers.

Work under the Contract shall continue during the Arbitration proceedings.

The award of the Arbitrator shall be final and binding on the parties. Upon every or any such reference, the costs of and incidental to the reference and award respectively shall be in the discretion of the Arbitrator, who may determine the amount thereof, or direct the same to be taxed as between Solicitor and Client, or as between party and party, and shall direct by whom and to whom, and in what manner the same shall be borne and paid. This submission shall be deemed to be a submission to Arbitration, within the meaning of the Arbitration Act, 1889.

To be included where the work is to be done wholly or partly abroad or in Scotland.

CONSTRUCTION OF CONTRACT—

48.—The Contract shall in all respects be construed and operate as an English Contract and in conformity with English law, and all payments thereunder shall be made in [England and in] sterling money.

FORM OF TENDER.

SECTION .

....

To the ....

Gentlemen,

.... the undersigned, do hereby offer to contract for the above-named Work, in accordance with the preceding General Conditions and Specification, at the prices which .... have submitted on the preceding page, and in case .... tender be accepted .... do hereby undertake and agree to execute a Contract in accordance with General Conditions, Clause 10, and .... propose as Sureties as required by that Clause ....

of ....

and ....

of ....

Dated .... day of .... 190 .

Signature ....

Address ....

....

List of Drawings submitted by Tenderer under Section :—

....

....

....

....

FORM OF AGREEMENT.

This Agreement made the day of 190

BETWEEN

(hereinafter referred to as the "Contractor") of the first part the

(hereinafter called the "Purchasers") of the second part and of

and

of

(hereinafter called the "Sureties") of the third part **Whereas** the Purchasers are about to erect and maintain the

hereinafter called

the "Works" mentioned enumerated or referred to in certain General Conditions Specification Drawings Form of Tender and Schedule of Prices and the further Specification entitled "Additional Details" which for the purpose of identification have been signed by

on behalf of the Contractor

and (the Engineer of the Purchasers) on behalf of the Purchasers **And Whereas** the Purchasers have accepted the Tender of the Contractor for the provision and execution of the

said works for the sum of
upon the terms and subject to the conditions hereinafter mentioned **And Whereas** the Sureties have agreed for the consideration hereinafter appearing to enter into the covenants hereinafter contained and on their part to be performed : **Now this Indenture Witnesseth** that in pursuance of the said Agreement and in consideration of the payments to be made to the Contractor by the Purchasers as hereinafter mentioned the Contractor hereby covenants with the Purchasers their successors and assigns that he shall and will duly provide erect and complete uphold and maintain the Works mentioned enumerated or referred to in the Contract and shall do and perform all other works and things therein mentioned or described or which are implied therefrom or therein respectively or may be necessary for the completion of the said Works within and at the times and in the manner and subject to the terms conditions and stipulations in the Contract mentioned and to the satisfaction of the Engineer for the time being

of the Purchasers and also will to the like satisfaction maintain the same in an efficient manner as mentioned in the Contract and shall and will observe and perform all the conditions and provisions set out in such Contract and that all the powers liberties rights and privileges mentioned therein and conferred thereby in respect of such Works shall and may be exercised according to the true intent and meaning thereof **And** in consideration of the due provision erection execution construction and completion of the said Works and the maintenance thereof as aforesaid and of the covenant of the Sureties hereinafter contained the Purchasers do hereby for themselves their successors and assigns covenant with the Contractor that they the Purchasers their successors and assigns will upon the certificates of the Engineer for the time being of the Purchasers pay to the Contractor the said sum of

or such other sum as may become payable to the Contractor under the provisions of the Contract such payments to be made at such time and in such manner as is provided by the Contract. And the Sureties at the request of the Contractor and in consideration of the Purchasers entering into this agreement do hereby jointly and severally covenant and guarantee with and to the Purchasers that the Covenant on the part of the Contractor in this Contract contained shall be well truly and faithfully performed by the Contractor in every respect according to the true intent and meaning of this Contract and that in the event of default on the part of the Contractor in respect of the performance in any particular of the said Contract the Sureties will pay to the Purchasers all such losses damages costs charges and expenses as the Purchasers may sustain incur or be put unto by or by reason or in consequence of any such default but so nevertheless that the total amount to be demanded or recovered by the Purchasers of or from the Sureties shall not exceed the sum of Ten per cent. of the total contract price.

Provided always and it is hereby covenanted agreed and declared between and by the parties hereto that these presents are entered into and the said Works are to be provided erected executed constructed completed and maintained upon and subject to the terms and conditions contained in the Contract **And** that the parties hereto respectively shall have such rights powers and liabilities and the said Engineer shall have such powers and authorities in respect of the said Plant and the tools and materials for the same and extension in respect of the Contract and all matters connected therewith as are given and expressed by and in the same terms and provisions of the Contract.

In Witness whereof etc.

INDEX TO GENERAL CONDITIONS.

JOURNAL

OF THE

Institution of Electrical Engineers.

Founded 1871. *Incorporated* 1883.

VOL. 32. 1903. NO. 160.

The Three Hundred and Eighty-Sixth Ordinary General Meeting of the Institution was held at the Institution of Civil Engineers, Great George Street, Westminster, on Thursday evening, January 22, 1903[1]—Mr. JAMES SWINBURNE, President, in the Chair.

The minutes of the Ordinary General Meeting held on January 8, 1903, were read and confirmed.

The names of new candidates for election into the Institution were announced, and it was ordered that their names should be suspended in the Library.

The following transfers were announced as having been approved by the Council :—

From the class of Associate Members to that of Members—

Arthur Brunel Chatwood.
Henry Mannington Sayers.

From the class of Associates to that of Members—

Albert Wilson Jones.
Arthur Jas. Stubbs.

From the class of Associates to that of Associate Members—

F. Biliotti.
Hy. Louis Victor Joly.
Walter James Leeming.
John Mark Auguste Margetts.
F. Tandy.
Edward Stanley Shoults.

From the class of Students to that of Associates—

William Gilbert Carter.
Geo. William Selwyn Driver.
Geo. Marinier.
Albert Henry Midgley.

The President announced that, owing to a misunderstanding, Mr. Graham T. Olver's name had been printed in the list of Associates,

[1] The discussion on the Metric System intervened between the reading of Mr. Scott's and Mr. Esson's papers on the 8th of January, and the discussion upon them ; but in order to preserve the continuity of the record in the Journal, the report of the meeting of the 8th of January has been printed after that of the meetings on the 22nd of January and the 5th of February (*vide* p. 328).

instead of in the list of Members, published in 1902, and that his name had now been restored to the Register of Members.

Messrs. J. O. Girdlestone and C. O. Grimshaw were appointed scrutineers of the ballot for the election of new members.

Donations to the *Building Fund* were announced as having been received since the last meeting from Messrs. A. W. Beuttell, I. Braby, J. B. Braithwaite, S. L. Brunton, A. Burton, G. B. Byng, Major P. Cardew, J. B. Edwards, C. F. Farlow, S. Z. de Ferranti, C. G. Friedelberg, R. F. Fuller, H. E. Harrison, D. Henriques, H. Hirst, P. Hunter Brown, E. Hutchinson, W. M. Mordey, D. S. Paxton, C. W. D. Peel, C. Poulsen, E. R. Rudge, P. W. Sankey, K. W. Sutherlands, A. D. Williamson, and L. Wood; and to the *Benevolent Fund* from Messrs. I. Braby, Major P. Cardew, H. C. Donovan, D. Henriques, W. J. S. Pyper, and E. B. Thornhill, to whom the thanks of the meeting were duly accorded.

The PRESIDENT: This evening we shall make a somewhat unusual arrangement. Nominally we are to have a discussion, but as far as we can we shall follow our practice of treating the first part as a paper: that is to say, I shall call upon Mr. Siemens to open the proceedings by reading his paper, and after that I shall call on Sir Frederick Bramwell to open the discussion in the form of a reply to Mr. Siemens; after that there will be a general discussion, and Mr. Siemens will be given an opportunity of summing up at the end.

I have now much pleasure in calling on Mr. Alexander Siemens to read his paper on the Metric system.

NOTES ON THE METRICAL SYSTEM OF WEIGHTS AND MEASURES.

By ALEXANDER SIEMENS, Past President.

On November 14th, 1783, James Watt wrote to his friend, Mr. Kirwan, about the trouble he had experienced in reducing the weights and measures, when comparing the experiments made by Lavoisier and Laplace with results obtained by Mr. Kirwan, and he continues:

> "It is, therefore, a very desirable thing to have these difficulties removed, and to get all philosophers to use pounds divided in the same manner, and I flatter myself that may be accomplished, if you, Dr. Priestley, and a few of the French experimenters will agree to it; for the utility is so evident that every thinking person must immediately be convinced of it. My proposal is briefly this:
>
> Let the philosophical pound consist of 10 ounces or 10,000 grains.
>
> „ ounce „ „ 10 drachms or 1,000 „
>
> „ drachm „ „ 100 grains or 100 „
>
> Let all elastic fluids be measured by the ounce measure of water, by which the valuation of different cubic inches will be avoided, and the common decimal tables of specific gravities will immediately give the weights of those elastic fluids."

After discussing the claims of various pounds, he concludes the letter by saying :

> "Dr. Priestley has agreed to this proposal, and has referred it to you to fix upon the pound, if you otherwise approve of it. I shall be happy to have your opinion of it as soon as convenient, and to concert with you the means of making it universal.—I remain, etc.
>
> "I have some hopes that the foot may be fixed by the pendulum, and a measure of water, and a pound derived from that ; but in the interim let us at least assume a proper division, which from the nature of it must be intelligible, as long as decimal arithmetic is used."

On November 23rd, 1783, James Watt wrote to M. de Luc on the same subject :

> " . . . Indeed to compare one experiment with another even where the weights used are the same, gives much trouble from the absurd subdivisions used by all Europe ; and also to compare cubic inches of various substances with weights is a perpetual source of unnecessary calculation ; in order to avoid which I proposed to Dr. Priestley and Mr. Kirwan to agree on a perpetual decimal subdivision of the pound thus :
>
> 100 grains = 1 drachm ; 1,000 grains = 1 ounce ;
> 10,000 grains = 1 pound.
>
> All the elastic fluids to be measured by the ounce or pound measure. The decimal tables of specific gravities will give the weights without calculations. All liquids to be weighed. Mr. Kirwan answers that Mr. Whitehurst is at work on a philosophical measure, from which he means to deduce a pound, divided as above ; but I say, as it may be long before that comes forth, let the expedient of the proper division take place in the meantime. Dr. Priestley will immediately adopt it, and I will be obliged to you to write to M. de Laplace on the subject. In order to introduce uniformity as much as we can, we mean to subdivide the Paris pound in 10,000 parts . . ."

These two letters have a special bearing on the subject which is to be discussed to-night, as Watt had laid down in them the fundamental conditions on which the metrical system is based.

It is even probable that Watt is directly responsible for the movement among French scientific men, for his biographer, Muirhead, tells us that in 1786 Watt and his partner, Boulton, went to Paris, and there "they had the satisfaction of making the acquaintance of most of the eminent men of science, of whom the great capital of France had then to boast, as Lavoisier, La Place, Monge, Berthollet, De Prony, Hassenfratz, Fourcroy, Delessert and others." No doubt Watt's idea of a "philosopher's pound" was discussed among them; at least it bore fruit, for in the year 1790 Prince Talleyrand proposed to the Constituent Assembly of France that the many systems in use in that country be changed into one system, and that be a decimal one founded

on the pendulum. This was adopted by the Assembly on the 17th of March, 1791, and sanctioned by Louis XVI.

It will be noted that this plan is foreshadowed in the postscript of Watt's letter to Kirwan, and a further indication of his influence may be traced in the provision that the French Academy and the Royal Society of Great Britain appoint jointly an International Commission for discussing the subject of universal weights and measures.

England declined, however, to co-operate, but Spain, Italy, the Netherlands, Denmark, and Switzerland were finally represented on this Commission, which consisted of the ablest mathematicians then living.

The system, suggested by Watt and adopted by this International Commission, derives the units of weight and of capacity from the linear standard, and the chief object of the Commission was to settle how the linear standard was to be fixed.

Three linear standards were discussed:

1. The length of a pendulum beating seconds.
2. The length of a quadrant of the equator.
3. The length of a quadrant of a meridian.

Eventually the last was selected, and it was decided that the ten-millionth part of this quadrant should be the linear unit, "the meter."

A law, passed on August 1st, 1793, established the system provisionally, and the nomenclature was sanctioned nearly two years later on April 7th, 1795.

For seven years the survey of the meridian between Barcelona and Dunkirk went on, until in 1799 representatives from ten countries assembled in France to examine the results of the survey, and to settle "a definite meter."

When this had been accomplished, Laplace explained the whole system to the legislative councils of France, and it was definitely adopted by a law promulgated on June 22nd, 1799.

Unfortunately, the succession of wars, undertaken at first by the Republic, and afterwards by Napoleon I., against all the other nations of Europe, was then in progress; moreover, Napoleon, personally, did not approve of the change, so it came about that an intermediate system of divisions and of names was tolerated by a law passed on May 28th, 1812.

The pure metrical system was not enforced in France until January 1st, 1840.

Other European countries were at first very reluctant to adopt the metrical weights and measures, but when the inter-communication between distant parts of the same country and between different countries developed during the nineteenth century, the want of uniformity in weights and measures grew more and more inconvenient.

In Germany, for instance, a Commission was appointed to settle a national unit of weights and measures, and it began its investigations in 1861. It was very soon decided, however, not to elaborate a national system, but to recommend the metrical system. The actual introduction was delayed by the wars of 1864 and 1866, and it was only in August, 1868, that a law was passed making the use of metrical weights

and measures optional from January 1st, 1870, and compulsory from January 1st, 1872.

While the German Commission was deliberating, a Select Committee was appointed by the House of Commons, and it reported in 1862 that in its opinion "it would involve almost as much difficulty to create a special decimal system of our own, as simply to adopt the metric decimal system in common with other nations. And if we did so create a national system we would, in all likelihood, have to change it again in a few years, as the commerce and intercourse between nations increased, into an international one."

In 1864 an Act was passed allowing the use of the metric system of weights and measures, and in 1868 a Bill was brought in to make this system compulsory, but the Bill was dropped after passing the second reading.

The Weights and Measures Act (1878) authorised the Board of Trade, by Clause 38, "to verify metric weights and measures which are intended to be used for the purposes of science or of manufacture or for any lawful purpose, not being for the purpose of trade within the meaning of this Act."

The provisions of this clause became more and more irksome, and another Select Committee was appointed in 1895, which, after examining numerous witnesses for and against the introduction of the metric system, recommended :

> "(*a*) That the metric system of weights and measures be at once legalised for all purposes.
>
> "(*b*) That after a lapse of two years the metric system be rendered compulsory by Act of Parliament.
>
> "(*c*) That the metric system of weights and measures be taught in all public elementary schools as a necessary and integral part of arithmetic, and that decimals be introduced at an earlier period of the school curriculum than is the case at present."

In consequence of this recommendation Parliament passed the Weights and Measures Act (1895), but this gives effect only to the first part of it, and we are still waiting for the Act to make the adoption of the metrical weights and measures compulsory.

The only practical steps towards the introduction of the metric system into the United Kingdom have been taken by the British Association, of which a Committee worked out the c.g.s. system of electrical units.

It is not necessary to say in this assembly that these units were subsequently adopted by the International Electrical Congress of Paris (1881), and that their general introduction into all countries has been one of the principal causes of the rapid development of the application of electricity for industrial purposes.

Another Committee of the British Association, consisting of Sir Joseph Whitworth, Sir Wm. Thomson (now Lord Kelvin), Sir F. J. Bramwell, Mr. A. Stroh, Mr. Beck, Mr. (now Sir) W. H. Preece, Mr. (now Colonel) R. E. Crompton, Mr. E. Rigg (secretary), Mr. A. Le Neve Foster, Mr. Latimer Clark, Mr. (now Sir) H. T. Wood and Mr. Buckney

was appointed for the purpose of determining a gauge for the manufacture of the various small screws, used in telegraphic and electrical apparatus, in clockwork and for analogous purposes.

After deliberating for two years this Committee recommended in 1884 the adoption of the Swiss series of small screws, commencing with the pitch of one millimeter, and decreasing the pitch of each succeeding size by 10 per cent.

In the United States by an Act of Congress, approved in July, 1866, the use of the weights and measures of the metric system is made permissible and the "international prototype meter and kilogramme" (deposited in Paris) are regarded as the fundamental standards of length and mass; and the yard and pound are to be derived from the metric standards.

It is proposed to bring in a Bill during the present session of Congress directing all Government departments to use the metrical system for all their transactions from January 1st, 1904, and making the system compulsory throughout the United States from January 1, 1907.

About other civilised states, apart from Great Britain and the United States, it is only necessary to say that they have adopted the metrical system on account of the simple relations between the units of length, of weight, and of measure, and on account of the decimal subdivision of the units which agrees with the arithmetical notation used universally.

The metrical system is, of course, not the only one by which these two advantages can be obtained; for instance, Sir John Herschel suggested a rival system by making the polar radius of the earth the unit of length.

This radius he estimated to be 500,500,000 inches long, and he suggested that the English inch should be increased by its $\frac{1}{1000}$ part, so that it should be exactly the 500 millionth part of the polar radius.

He then undertook to show that by increasing the grain (by legislative measure) by its $\frac{1}{18}$ part a cubic foot of water would weigh a thousand ounces.

> "And thus the change, which would place our system of linear measure on a perfectly faultless basis, would at the same time rescue our weights and measures of capacity from their present utter confusion, and secure that other advantage, second only to the former, of connecting them decimally with that system on a regular, intelligible and easily-remembered principle; and that by an alteration practically imperceptible in both cases and interfering with no one of our usages and denominations."

In this proposal Herschel committed the same error as the compilers of the metrical system by adopting a terrestrial dimension as a "perfectly faultless" basis for his linear standard; in both cases later measurements with improved instruments have proved that the original results were not accurate.

With regard to the decimal subdivision of the units, Sir George Airy, the late Astronomer Royal, said :

> "It appears to me that the practice of mankind, as regards their selection of scales of multiples and subdivisions, in every subject which I have examined, may be described thus: For each particular subject to which measure, etc., is applied some one measure, etc., is adopted as the standard. Then the multiples of this measure, etc., are taken on the decimal scale, and the subdivisions are taken on the binary scale. These subdivisions are taken without any regard to their coincidence or non-coincidence with inferior measures, etc. The coasting sailor uses the league, $\frac{1}{2}$ league, $\frac{1}{4}$ league, without regard to miles or yards. The traveller uses the mile, $\frac{1}{2}$ mile, $\frac{1}{4}$ mile, furlong, and never combines them with the yard or the foot. The sailor, in sounding, uses the fathom, $\frac{1}{2}$ fathom, $\frac{1}{4}$ fathom, and thinks of no other measure. The vendor of drapery uses the yard, $\frac{1}{2}$ yard, $\frac{1}{4}$ yard, etc., down to the nail, without regard to inches. The joiner uses multiples of inches to a large number and subdivides the inch to $\frac{1}{2}$, $\frac{1}{4}$, $\frac{1}{8}$, $\frac{1}{16}$. . . . It is very little important whether the relation between the standards adopted for the different measures (for instance, the mile and the yard) be or be not simple, provided that it be ascertained."

Then Sir George Airy also said in his evidence before the Select Committee of 1862 :

> "If I had a new nation to create, with a new style of weights and measures, I would give them the binary scale throughout; that I consider nearest perfection, with means to enable us to use decimal multiples and sub-multiples."

Curiously enough, these statements of Sir George Airy were laid before the Select Committcee of 1895 by Mr. Stevenson as adverse to the metrical system.

A little reflection will, however, convince everybody that the metrical system fulfils all the requirements laid down by Sir George Airy, with the additional advantage that the standards for the different measures stand in a simple decimal relation to each other.

For instance, a traveller might use a km., $\frac{1}{2}$ km. and $\frac{1}{4}$ km.; a joiner will use millimeters or $\frac{1}{2}$ and $\frac{1}{4}$ mm.; a merchant kg. for ordinary transactions, and tons for larger transactions, subdividing them on the binary scale, whenever he finds that convenient.

In most transactions, according to metrical weights and measures, no fractions are necessary, either vulgar or decimal, as the smallest units, the milligramme and the millimeter, need not be subdivided for ordinary purposes, and their multiples can be readily expressed in higher units, if that should be desired.

For this reason it may be anticipated that the introduction of the metrical system would cause no inconvenience; especially not in the retail trade.

The experience of other countries, which have made the change to the metrical system, proves that the initial difficulties of the transition from the old weights and measures can easily be met by providing conversion tables, which should be displayed in conspicuous positions in all shops.

It so happens that the principal changes which concern the retail trade, viz., from the yard to the meter, and from the lb. to the ½ kg. (metrical pound), are very simple.

The meter is about $\frac{1}{12}$ longer than the yard, the cost per meter is, therefore, 1d. per shilling greater and the metrical pound is a little more than 10 per cent. heavier than the pound avoirdupois, so that the cost of the ½ kilo. exceeds the cost of a pound avoirdupois by 1¼d. in the shilling.

If the customer, therefore, does not wish to rely on the conversion table, he can calculate the price, as if he were dealing with yards or pounds, and then add in the first case 1d. for each shilling of the result and in the case of the pounds 1¼d. for each shilling.

Although such a conversion is not absolutely accurate the difference is much smaller than the fluctuations of wholesale prices.

Again, the coil of 110 yards is only 23 inches (or 0·58 per cent.) longer than 100 meters, so that the substitution of the one for the other need not cause any inconvenience.

In spite of all these facilities it is only natural that the use of new weights and measures, as long as they are unfamiliar, will contrast unfavourably with dealings in the old weights and measures, but the public will soon find out what a blessing the abolition of the various and perplexing tables of weights and measures will prove to be, and how superior the metrical system is.

This opinion was tersely expressed by Mr. Balfour, when he said to a deputation which urged him to carry out the recommendation of the Select Committee of 1895:

> "Upon the merits of the case I think there can be no doubt whatever, that the judgment of the whole civilised world, not excluding countries which still adhere to the antiquated systems under which we suffer, has long decided that the metric system is the only rational system."

The President. The PRESIDENT: I now call on Sir Frederick Bramwell to open the case for the other side.

Sir Fredk. Bramwell. Sir FREDERICK BRAMWELL, Bart., F.R.S.: Mr. Siemens starts off with the history of the metrical system, about which I have nothing to complain. He says it is due to the most eminent mathematicians of the day. You will find that Napoleon had something to say upon that point. The law was passed in June, 1799; and Mr. Siemens attributes to the continued wars and to the ill-will of Napoleon the fact that the law did not come into operation until 1840—forty years later. I can remember very well its coming into operation, and I remember it by reason of a bad joke which often makes a very good memory point for me. There was a French paper then published in London called the *Courier de l'Europe*, to which I subscribed, and they pretended that a gentleman whose name was Mr. Vingtsous had written that name over

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his shop, and was haled before the magistrate for having infringed the law. He said: "What am I to do? I am going to be married to-morrow. What am I to call myself; what ought I to have written up?" "You ought to have written up Franc, and not Vingtsous." "Am I to call myself Mr. Franc when I marry!" That is why I remember when the law came into force. The use of the system was permitted in England in 1864, and the Act of 1878 allowed the Board of Trade to verify the weights and measures. There was a Committee appointed in 1895 to consider the metric system; this Committee has been alluded to by Mr. Siemens. I have a complaint to make against the Committee. A gentleman came forward and gave a calculation of a sum carried out metrically, and also in the way he was pleased to call the ordinary way. It could only have been done from gross ignorance or from malice prepense. I put in a counter calculation of the true ordinary way; and, whereas he had succeeded in showing that according to his ordinary way the number of figures employed exceeded those used in the decimal mode by, I do not know what multiple—double, I think—I showed that according to the real ordinary way the number of figures employed was half the decimal mode number of figures. That calculation the Committee refused to publish; it is not there in the evidence, and I had recourse to the *Times* to get it before the public. Now this is a little bit of over-zeal which I think it might have been well to have left out. The Committee came to the three conclusions stated by Mr. Siemens: (*a*) That the metric system of weights and measures be at once legalised for all purposes. (*b*) That after a lapse of two years the metric system be rendered compulsory by Act of Parliament. (*c*) That the metric system of weights and measures be taught in all public elementary schools as a necessary and integral part of arithmetic, and that decimals be introduced at an earlier period of the school curriculum than is the case at present. We have now, in the Act of 1897, arrived at the outcome, so far, of that Committee's conclusions. What says that Act? Stated shortly, it says: "Notwithstanding anything in the Weights and Measures Act, 1878, the use in trade of a weight or measure of the metric system shall be lawful, and no person by reason of using or having in his possession a weight or measure of the metric system shall by reason thereof be liable to a fine. The Board of Trade standards, which may be made under Section 8 of the Weights and Measures Act, 1878, shall include metric standards derived from the original platinum linear standard metre, and original platinum standard kilogramme deposited at the Board of Trade and numbered 16 and 18 respectively. It shall be lawful for the Queen by order in Council to make a table of metric equivalents." In the following year the Council did make a table of metrical equivalents, and here they are, but I do not think I can usefully take up your time by reading them to you. That is what has come of the recommendation of the Committee of 1895 up to the present moment. Now Mr. Siemens very frankly says that his desire is that letter (*b*) of the Committee's recommendation—that after a lapse of two years the metric system be rendered compulsory by Act of Parliament—should be adopted. That really is the question before the meeting to-night. Perhaps Mr.

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Siemens has seen a copy of the proposed Bill. I have not; I can only judge from that of 1868. Now the Bill was not to be a mere matter of words; it was to be very stringent and very troublesome indeed. Section 10, stated shortly, provided that "Every person who shall sell otherwise than by the metric system shall be liable to a penalty not exceeding 40s. for each sale." Section 11: "Every person who shall print, who shall make any return as Clerk of the Market, price list, price current except metric shall pay any sum not exceeding 10s. for each copy of such paper." Therefore the unhappy gentleman who had made a blunder of that kind might very soon, if he had printed a thousand papers, find himself fined £500! That is the kind of thing we may expect, I suppose, and I do not say it is unreasonable from the point of view of the "Metrics"; from the point of view of a gentleman who believes that you could not go to heaven if you did not profess certain things, it is not unreasonable to torture your body, because your soul is worth more than your body and the benefit to the soul outweighs the bodily torture. But this kind of thing, you know, does away with the question of the survival of the fittest. I thought in these days we had come to regard the survival of the fittest as being the absolute test of the value of any system. The advocates of the metric system can now, after this Act of 1897, do what they like—have their weights, keep their accounts, do everything that they please. "No," they said, "that will not do for us. You shall use the metric system, whether you like it or not." That is not the survival of the fittest, and it is inconsistent with anything like liberty. The only thing of which it reminds one is the now somewhat old tale of the man who said "Sir, this is the freest country on earth; every man does as he likes, and if he does not we make him." Mr. Siemens goes on to state that the system is now pretty nearly adopted all over Europe except in Russia. I am sorry to say that is so, but so it is; I cannot contradict it. [Mr. SIEMENS: These clauses are taken from the other Acts; they are taken from the Weights and Measures Acts which are in force, enforcing the English weights. It is the same clause.[1]] One can see why Germany adopted the metric system. Germany was made up of a number of States—so was Italy, by the bye—with divers laws and regulations. They were compelled to come to some one system, and no one of those small States could have devised a system which would have been taken up by the whole Empire; therefore they were glad to adopt that system which was to their hand. I am surprised to find that Mr. Siemens has not put forward the usual plea, which, to my mind, is the only one that has even the shadow of a value in it, namely, that our merchants and manufacturers are handicapped in their dealings with foreign nations because the foreign nations do not understand our measurement—they know about our coinage—in which we deal with them. Whose fault is that? Is it not the fault of the merchant? He may do what he likes with the metric.

[1] (*Note added January 29th.*)—The reply to the above remark of Mr. Siemens is that so long as such clauses applied to existing weights and measures, there was but little chance of them being infringed, and therefore little chance of the penalties being imposed; but, when applied to the introduction of a new system, both infringement and penalty would follow, as a matter of course, for years to come.

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No, that will not do for him. He says "No; all of you shall be compelled to deal in metric; I am not going to do it by myself, but you shall all do it." That kind of answer is so obviously wrong, and the suggestion that the whole difficulty can be met by the merchants themselves so very clear, that I am not surprised Mr. Siemens did not put this stock objection forward; he knew the comment that the merchants had the remedy in their own hands was unanswerable.

Mr. Siemens says that the Bill of 1868 was dropped, and refers to Sir George Airy and Sir John Herschel. I am inclined to think that Mr. Siemens has misquoted both those gentlemen—quite unintentionally, I am sure. Sir George Airy is being examined before the Committee of 1862 and very much pressed by the Chairman. Mr. Siemens has quoted one answer: "If I had a new nation to create, with a new style of weights and measures, I would give them the binary scale throughout." That does not look much like decimals; he then goes on—I cannot quite understand what he means—"That I consider nearest perfection, with means to enable us to use decimal multiples and sub-multiples." But he would start with the binary scale. That was in answer to Question 1968. Mr. Siemens did not quote the previous Question, 1967, when the Chairman endeavoured to force Sir George Airy's assent to the decimal system. This is the question and answer: "*Q.* But if the change"—that is, to the decimal system—"could be made *per saltum* and you could be transferred from your present state into the decimal system, do not you think the change would be advantageous? *A. No.*" That does not look very much like Sir George Airy being an advocate of the decimal system—the question of the metric system did not then appear to arise.

Now as regards Sir John Herschel. Writing on the 6th of April, 1868, to Mr. Beresford Hope on the Bill of 1868 for the compulsory use of the metric, he said, "Pray pardon me for calling your attention to this Bill of Ewart's . . . . in the hopes that you will oppose it at all events by vote, and perhaps by words." That does not look like Sir John Herschel being an advocate of the metric system. Beresford Hope did oppose it. I wish that time permitted me to read the whole speech to you, but it does not. He complains of the proposed compulsory use of decimals, and then still more earnestly of the compulsory use of the metric system, with its Greek and Latin terms. Although I cannot read the whole speech, may I read the following extracts:—

EXTRACT FROM "HANSARD'S PARLIAMENTARY DEBATES," VOLUME 192.

"But I may be told—Halve away, but then express your halvings in decimals. This is very easy for the merchant prince to do when he is totting up his large transactions in 'centals,' or for the Chancellor of the Exchequer when dealing with a nation's finances; but how will it suit the little transactions of daily life? I come back to my loaf. How are ordinary people to represent halves and quarters by decimal points? The symbol of a half is the figure 'five,' with a dot to its left hand; the symbol of half that quantity—that is of a quarter—is the sum twenty-five, also with a dot to its left hand. Arithmeticians understand how this can come about, and the symbols have grown natural in their eyes; but in what—even the most infinitesimal—degree do they tell their own story to the unlearned? What palpable

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relations towards each other can be disentangled out of these most frequently recurring symbols? What is there in the nature of things to show that the dotted five means a half, and the dotted twenty-five a half of that half, and a quarter of the 'one,' with no dot on either side, which stands for unity? Decimal notation is then, after all, as I have been arguing, a process, and not a system. It is a process good for the schools, and good for the bustling counting-house and the large sum, but the poor man would be completely thrown out if he had to employ—under penal legislation, too—decimal points for the purpose of measuring his little purchases by halves and quarters."—(Page 188.)

"One-tenth part of this gram is to be a decigram, and ten times a gram is to be a dekagram, for the reformers decreed that aliquot parts were to be named after the Latin, and multiples after the Greek numerals. How in the name of common sense can we make poor people understand that because there are the letters 'ci' in the one word it means the tenth of a gram, and that because there are the letters 'ka' in the other it means ten grams, or 100 decigrams? My hon. friends the Member for Dumfries and the Member for Liverpool come to this House representing great commercial transactions; but I stand up for the poor man. Only imagine an honest housewife going into a shop and asking for a decigram of pepper, and a dekagram of tea; imagine, too, the milkmaid selling her fluid by the litre. The Member for Liverpool is a kind-hearted man; is he then prepared, with all the stringent force of a penal statute, to enact that when one of his youthful constituents may desire to effect a commercial transaction in a manufacture for which one portion of that great borough is famous, he should be bound to go to the shop and tender his 'dime' for three decigrams of Everton toffee? Fancy the farmer, who has been accustomed ever since he entered on his farm to cultivate the 'ten-' or the 'twelve-acre field,' having to consult the steward about liming the seventeen-are field, or be a criminal and a contemner of the laws of his country. Fancy the bumpkin who was prepared to boast that he was within a decimeter of catching the fox as he crept through a gap about a dekameter from the white gate. If the theorists and the men of wealth—men of brains, it may be, but as certainly men of self-assurance—have worked out this system for themselves, there are poor men, who form the majority of mankind, for whom it will never answer, and there are men of brains at least equal who are decidedly opposed to its adoption."—(Page 189.)

I think this speech contains about the best common sense, and is one of the most convincing speeches I have ever read.

Mr. Siemens wants the compulsory metric system pure and simple. He has not dealt to any extent with the decimal question; but the decimal question being an inevitable part of the metric system, I must deal with decimals. I believe a good many of my friends imagine I am an opponent of decimals. I am nothing of the sort; I cannot do without them; I should be greatly troubled to extract a square root or cube root without them; and without them I could not use logarithms. I want this to be borne in mind: that of which I am an opponent is not decimals, but the compulsory use of them on all occasions. It is that to which I object. Modes of calculation are only tools to attain an end. Imagine a carpenter with a bag of tools, including an adze, meeting an enthusiast about what can be done with an adze. The enthusiast says to the carpenter: "You shall use that adze on all occasions." "Oh," the carpenter says, "nonsense; I have other tools which at other times are more convenient." "I do not care; it shall be illegal if you use any other tool than an adze." I suppose that anybody who brought that forward would be promptly sent to Bedlam. It is the same thing with the obligation to use decimals on all occasions. Remember, a decimal is nothing but a vulgar fraction with a denominator of always

one kind; you do not write the denominator, but you indicate by the position of the decimal point, if you know how, what the real denominator would have been if you had written it. You have one more figure in the denominator than you have up above. When you get a point and the figure (·1), there is in the denominator one more figure than the 1, viz. the 0, and you would write as a vulgar fraction $\frac{1}{10}$; the denominator has two figures, that is one more than the numerator, which has only one figure. When you write decimally a $\frac{1}{100}$ you put ·01; you have one more figure in the denominator than you have in the numerator above, and so on. Very much practice is needed to insure the accuracy of the point before the significant figure; I think most of you who have had anything to do with the decimal calculations will admit that. Sir Fredk. Bramwell.

May I worry you with one or two instances. In 1885 a paper was read in this room before the Institution of Civil Engineers. A large illustrated diagram was put up, which was illustrative of decimals. I found that the decimal point was in the wrong place. That was a specimen diagram!

Then I had a correspondence in the *Times* some two or three years ago with a Frenchman stopping in London upon questions of decimals, and he chaffed me in his letter at my clumsy mode of taking off 2½ per cent. What do you think he said he would do? He said, "All that I should have to do would be to multiply by 97·5." I said that all I had to do was to take off $\frac{1}{40}$th—2½ per cent.

I will give you another case that came under my own knowledge; I did not bring the papers here, but I have re-looked at them. In 1897 there was an arbitration between a Water Company and a Local Board; I was umpire in the ascertaining of the sum to be paid. There had been a previous hearing to find out whether the Company was in default on the ground of not being able to give sufficient water. The population of the district was almost exclusively composed of working miners, and among the demands made was one of 4 gallons per head for manufacturing purposes in a population of working miners. The Company were declared in default, and the Local Board stepped in. When they came before me to determine the sum to be paid, the counsel who opened the case for the Company said, blushing, "I am very sorry. There was a great mistake which nobody on either side found out: that 4 gallons was not 4 gallons at all; it was ·4"; that was stated also by the first witness who appeared for the Company. Therefore, here there is an instance of a body of eminent barristers and of eminent engineers working together, and all blundering over the decimal point.

Then there was a communication in the newspaper when the now King was shot at in Brussels; it came from the Continent, and, I believe, from a metric-using country. They reported that the bullet was ·1 metre long. I tried to put that length of metal into a revolver, and found that not only would such a bullet have filled the whole length of the barrel, but that it would have projected to about an equal length. I cannot help feeling that many of us are in the position of the man whom his friend found figuring away to the ninth or tenth place of decimals; and when the friend said to him, "Why

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are you taking all this trouble; no such accuracy as this is needed for this case?" he replied, "The fact is I am by no means sure of my first figure on the left hand, but I am determined to cure any mistakes by going on." As I say, I like decimals when they are in the right place, but not otherwise.

On many occasions I find it better, and mankind has found it better, to use $\frac{1}{2}$, $\frac{1}{3}$, and so on; that is to say, that whereas the decimal is a vulgar fraction with a denominator always of the same kind, these vulgar fractions have the numerators always of the same kind, namely, 1, and especially mankind will use these vulgar fractions when the fractions are arrived at by repeated divisions by 2, and will not use ·5, ·25. I remember in a farce there was introduced a clerk who was a joint clerk to four briefless young barristers, who was called by each of them "·25," showing that the decimal system had reached the law. Humanity jibs even at ·5 and ·25; but when you get to $\frac{1}{8}$ (·125) it is a little complex: $\frac{1}{16}$ (·0625) is still worse; $\frac{1}{32}$ (·03125) is "worser"; and $\frac{1}{64}$—all these figures are legitimate divisions and are used in respect of shares in ships and so on—(·015625) is still worse. They are terribly unwieldy, but they are accurate. But when we come to the other fractions—$\frac{1}{3}$, $\frac{1}{6}$, $\frac{1}{7}$, and $\frac{1}{9}$—they are both unwieldy and inaccurate, and yet I am to be compelled to use them when I do not want to do so. The worst case, of course, is the $\frac{1}{7}$ (0·142857). For men like the late G. P. Bidder and Zerah Colbourne, and for some ladies now living, such a mass of figures as these present no difficulty, but to me they are insuperable. I can now only do the most rudimentary mental calculations; when I was younger I could do them pretty well, and I found them of the greatest possible use. Are there any gentlemen in this room who can mentally square 3·142857 ($3\frac{1}{7}$) and give the result in decimals? I should be very glad and very much surprised if any one of you will get up and do it. Suppose I wanted to square $3\frac{1}{7}$, and am allowed to use the vulgar fraction; it is done in a moment: 3 times 3 are 9, 3 times $\frac{1}{7}$ twice over are $\frac{6}{7}$, and $\frac{1}{7}$ of a $\frac{1}{7}$ is $\frac{1}{49} = 9\frac{43}{49}$. I cannot square mentally 4·875, but I can square mentally $4\frac{7}{8}$ ($23\frac{49}{64}$).

In this particular I appeal to all of you who have travelled, as every one has in these days, whether it is not the fact that the clerk at the ticket-office of a foreign railway is compelled on the simplest question of multiple-tickets or of multiple-conditions of ticket, to take a piece of chalk or a pencil and make a calculation before the amount to be paid can be stated. Compare that with an English railway clerk. You say, "Two firsts from A. to B., two thirds, and a child;" and he will mentally calculate it immediately, and accurately. Together with my wife I came from Marseilles to Paris some years ago. I thought that at Marseilles they had charged a very high fare, although I simply took two first-class tickets. I was right; their arithmetic was wrong owing to their upbringing, but their honesty was everything to be desired, for when we reached Paris I was asked, "Did you pay so-and-so at Marseilles?" "Yes," I replied, and I had the extra money returned to me. Their honesty could not be improved, even by vulgar fractions, but with the vulgar fractions they would not have made the mistake. Again, take an English butcher's wife or daughter: $9\frac{1}{4}$ lbs. of mutton at $10\frac{1}{2}$d.—it is

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done in a moment. I shall be glad if any one will tell me what assistance decimals are in any one of the four rules of arithmetic, except in the addition of such matters as £ s. d., or feet and inches. They are no good in division, they are no good in subtraction, and they are the very . . . . in multiplication. No doubt in £ s. d. and feet and inches they do save the mental division by 12 and by 20, but I regret that saving, because it gets rid of a perpetual opportunity of doing a little mental arithmetic, and I deprecate anything that does away with the use of mental arithmetic.

I have dealt at length with decimals because they are involved in the metric system. Not only does the metric system trouble one with decimals on all occasions, but you have the new fantastic terms in Greek and Latin to which Beresford Hope alluded. As I have said before, a merchant can adopt the metric system if he pleases, but why is it to be imposed on tradesmen and workmen? I will give you some notion of the magnitude of our ordinary weights and measures. Mr. Chaney, the Warden of the Standards—this, I believe, is the title of the gentleman who, at the Board of Trade, looks after the weights and measures—said before the Committee of 1895 that in the year 1893-4 they had stamped 3½ million individual weights or measures. That gives you some idea of the mere year's output in weights and measures, and what the extent of the change would be and how great the annoyance. It would be an intolerable annoyance, and to my mind even sumptuary laws would be preferable. I would very much rather the Government legislated upon the shape of my hat or the make of it, or upon the material of my coat and the "cut" of it, than that they should legislate upon the way in which I should make my calculations.

Mr. Siemens brought forward some eminent names in his favour, but not their arguments. The scientific man fed on French and German books, the merchant, often a foreigner or of foreign descent, too lazy to use the metric system themselves, want to inflict it upon the whole of us. Mr. Siemens quoted Sir George Airy as being in favour of decimals. I think I settled that matter. Airy said "*No.*" "Would not it be a benefit?" "*No!*" As regards Herschel, I have already said he wrote to Beresford Hope, "For heaven's sake go and speak in the House and stop this Bill for the compulsory use of the metric system."

Now may I refer to Mr. Coleman Sellers. I need hardly tell you that he is the Whitworth of the United States? He tried the metric system for twenty years in one department of his works, and condemned it. Rankine, again, is not a bad name to quote. His feeling in opposition to the metric system was so great that he broke into poetry, the celebrated "Song of the three-foot rule," the concluding lines of which are—

> "Oh, bless their eyes, if ever they tries
> To put down the three-foot rule."

I cannot help thinking that the second word of the first line must be a typographical error! I beg your indulgence for a short time while I deal with Napoleon. I have felt that his views on the matter, written by General Comte de Montholon, were so pertinent that I have taken

Sir Fredk. Bramwell.

the trouble to extract them from the work, and to have them printed in the French. I have prepared a somewhat loose translation in English, but loose as it may be I think it expresses the real meaning of the French. Napoleon says:—

1. The need of uniformity in weights and measures has been felt throughout all ages; several times the États Generaux have alluded to it. It was expected the Revolution would achieve this unification.

2. The law needed for this matter was so simple that it could have been written out in twenty-four hours, and could have been adopted and put into practice throughout the whole of France in less than a year. All that was required was to make the Units of Weights and Measures of Paris the only legal units throughout France.

3. The Government, the artisans, had for generations past used these weights and measures. By sending standards to every Commune, and by ordering the Administration and the Tribunals not to recognise any others, this reform would have been carried out without trouble, inconvenience, or coercive measures.

4. The geometers, the algebraists, were consulted in a question which was, in fact, purely one of an administrative character. They thought that the unity of weights and measures should be deduced from some natural order, so that it might be adopted by all the nations.

5. They were of opinion that it would not suffice merely to do good to forty millions of men, they wished the whole universe to participate.

6. They found the mètre to be an aliquot part of the meridian. They proved it (to their own satisfaction), and proclaimed it in an assembly of French, Italian, Spanish and Dutch geometers.

7. A new unit of weights and measures was immediately decreed which neither "fitted in" with the regulations of the Public Services, nor with the "rules and tables" of the manufacturers, nor with the dimensions of any existing machine.

8. Moreover, as a fact, the advantages of this system could not extend to the whole universe. It was impossible. The national spirit of the English and of the Germans was opposed to it.

9. If Gregory VII., in reforming the Calendar, was able to render that reformation universal throughout Europe, it was because this reform was connected with religious ideas; that it had not been made by a nation, but by the power of the Church.

10. Thus the comfort of the present generation was sacrificed to abstraction and to vain hopes, because, for an old nation to adopt a new unit of weights and measures, it is needful to remake all rules of public administration, all the calculations used in the arts. Such a work alarms the reason.

11. The new unit of weights and measures, such as it was, had an ascending and a descending scale, which did not tie in by simple numbers with the scale of the units of weights and measures which for centuries has sufficed for the Government, the scientific men, and the manufacturers.

12. The translation cannot be made from one to the other system, because that which is expressed by the most simple numerals in the old system demands, in the new, composite figures.

13. It became necessary, therefore, either to increase or diminish, by some fractions, in order that the measurement, or the weight, when expressed in the new nomenclature, should be in simple figures.

14. Thus, for example, a soldier's ration is expressed in the ancient nomenclature as 24 oz. This is a very simple expression; translated into the new, it gives 734 grammes, 259 milles.

15. Thus it is evident that to arrive at the whole numbers (734 or 735 grammes), there must be augmentation or diminution.

16. All the pieces and lines relating to architecture; all the tools and the parts used in clockwork, in jewellery, in publishing, in all the arts, in all the instruments, in all the machines, had been studied and calculated in the ancient nomenclature, and are expressed by simple numbers, while the translation needed numbers composed of five or six figures; thus all must be done

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over again. The "savants" conceived another idea, altogether nullifying the benefits of unity of weights and measures, for they adopted in their scheme the decimal numeration; they took the mètre as their unit, and they suppressed all other starting points.

17. Nothing can be more contrary to the organisation of the mind, the memory, and the imagination.

18. A fathom, a foot, an inch, a line, a point ($\frac{1}{12}$th of a line), are fixed portions of length, which the imagination readily conceives independently of their relation to one another. If, therefore, one asks for one-third of an inch, the mind operates immediately; it is a portion of length called an inch which is to be divided into three equal parts.

19. By the new system, on the contrary, it is not the operation of dividing an inch into three which has to be performed by the mind; but it is the division of a mètre into 111 parts. The experience of ages has shown the difficulty of dividing a distance or a weight beyond 12, for at each of these divisions there has been created a new "term" or starting point.

20. If one wanted the $\frac{1}{12}$th part of an inch, the operation was already made; it was the "term" "ligne."

21. Decimal numeration could (under the old system) be applied to all the "terms," and if an hundredth of a "point" or of a "ligne" was required, one wrote $\frac{1}{100}$th; but if one wishes to express an hundredth of a "ligne" by the new system one has to consider its relation to the mètre, which causes endless calculation.

22. The divisor 12 has always been preferred to the divisor 10, because 10 has only 2 factors—2 and 5; while 12 has 4, viz., 2, 3, 4 and 6. It is true that the decimal numeration, generalised and exclusively adapted to the mètre, as unity, affords facilities to astronomers and to mathematicians, but these advantages are far from compensating for the inconvenience of rendering the thinking-out more difficult.

23. The first object of every method should be to aid conception and imagination, to assist the memory, and to give greater power to the mind.

24. The various "terms" are as old as man, because they are in the very nature of his organisation, just as it is in the nature of decimal numeration to adapt itself to each unity, and to each "term," and not to one unit exclusively.

Further, these scientific men used Greek roots, thereby augmenting the difficulty. Such denominations, though they may be serviceable to the scientists, are not good for the public.

The "Weights and Measures" were among the great affairs of the Directoire.

Instead of leaving it to the influence of time, and of contenting themselves with encouraging the new system, by means of example and of custom, they make coercive laws, which were executed with vigour.

The merchants and the people found themselves harassed for that which was in fact a matter of indifference. This contributed still further to make unpopular an administration which placed itself aloof from the wants and the powers of the people; which violently broke their practice, their habits and their customs; just as might have been done by a Greek or Tartar conqueror, who, with the rod of power uplifted, enforced obedience to his will, who commanded according to his prejudices and his interests, regardless of those of the vanquished.

The new system of weights and measures will be the source of embarrassment and difficulty for many generations, and it is probable that the first scientific commission to whom it is given to verify the measurements of the meridian will find some corrections to make. It is a tormenting of the people for mere trifles.

I have the honour entirely to agree with Napoleon upon those points.

Now, what are the facts? The intended enumeration was meant to be the millimetre expressed by 0·001. But this is not used. People write m.m. Again, the centimetre: nowadays they do not write 0·01, but when dealing with capacity they write c.c. I thought they were County Councillors when I saw it first. Thousand kilos., is not used —a new name, a tonne.

Sir Fredk. Bramwell.

May I ask your indulgence for another ·0833′ of an hour, or better, as an hour is not a decimal portion of a day, for another ·00347 of a day?

It is very good of you to accord it to me, but I question how many of you knew that I asked for five minutes.

I will use these five minutes to call your attention to the sacrifice we should make of the short cuts that we have come to from the practice of years. I am too old a dog to learn new tricks; it would take me some time to find similar short cuts with the metric system. These are some of the short cuts with our present weights and measures:— A foot super of iron, $\frac{1}{8}$ in. thick equals 5 lbs. Cubic inches of cast iron, divide by 4 and add $\frac{1}{20}$th you get lbs. In round iron you only want to know the diameter in eighths and you get the weight in feet immediately. Take for example $1\frac{3}{8}$. That is $\frac{11}{8}$ths. Square 11 = 121, divide by 25, or multiply by ·4, equals 4·84 lbs. per foot. That is a short cut in which you may usefully employ a decimal. One cubic foot of water = $62\frac{1}{2}$ lbs. = 1,000 ounces. One inch deep of water off an acre is 101 tons; an inch off a square mile in a year is 40,000 gallons per diem. Every yard stroke made by a pump gives you a lb. for each circular inch. Thus an 8 in. pump, 8 times 8, 64, 6·4 gallons for each yard. I use the ·4 when I want to. A halfpenny laid on an inch ordnance map covers 500 acres. Nothing has been said by Mr. Siemens about the multiplicity of British local weights and measures, a complaint which has been so commonly made by the advocates of the metric system, and therefore as he has not said anything about it I need not say to him in popular language, "You're another." But it is a question which, if it had arisen, I should have asked permission to read extracts from a letter from the *Times* of the 13th of April, 1896, from our member, Mr. Robert K. Gray; it is a pity it should be lost. It is as follows:—

> This ordonnance, be it remarked, was issued about forty-four years after the metric and decimal system was devised, and is now fifty-seven years old. One might suppose that these 101 years would have sufficed to make the use of the system general in France, but this is not so. Precious stones are to-day bought and sold in carats; firewood in cordes; milk in pintes; gravel in toises; grain, potatoes, and charcoal in boisseaux; wine in barriques, feuillettes, demi-setiers, and chopines; wood for construction in pieds, pouces, and lignes; beer in canettes and pots; sugar and tea among the poor people is dealt with in livres, demi-livres, &c. Cattle dealing is carried on in pistoles and écus, and not in francs.
>
> * * * * * * *
>
> The jeweller in exercising his trade finds a carat a very serviceable unit, and no doubt the student of exact sciences finds the decimal relations between the units which exist in the metric system a great advantage; but why this jeweller should insist on the students adopting the units the jeweller finds best, or *vice-versa*, I fail to see.
>
> The weight of a truckload of coals can hardly be conveniently expressed in carats, and as the greatest weight mentioned in the metric system is the myriagramme of approximately 220 lb., this system is also unserviceable for dealings in large weights.

I think that will answer any objection that the metric system has not secured uniformity among the traders in France.

One final remark. In the Press and before the public the advocate of change is always at an advantage over the advocate of leaving things

as they are. The advocate of change wants something different, and therefore he cries out for it, and you hear all the noise he makes. People who are content with the present thing do not go about crying out "We are contented," and therefore you do not hear them, although their opinions are there in larger numbers probably than those of the persons who want the change. I do beg of you to bear this in mind when you see it said "that at an enthusiastic meeting So-and-so said so-and-so, and So-and-so said so-and-so," and to remember that you cannot get people who are content with that which exists to go to an enthusiastic meeting; they do not believe it will be of any use, and they say "What is the good of going to hear that nonsense." People do talk that kind of thing. Sir Fredk. Bramwell.

I wish, Mr. President, to thank you and the members present for the great patience with which you have listened to me.

The PRESIDENT announced that the scrutineers reported the following candidates to have been duly elected:— The President.

Member.

Arthur Moore Thompson.

Associate Members.

John Martin Blair.
Edwin Edwards.
George Henry Gibson.
Archibald John Hedgecock.
Charles Tranter Linney.
Arthur Edwin McKenzie.
Arthur Mills.
Sven Norberg.
Ernest Edward Smeeton.
Adamson George Wild.

Associates.

John Meikle Boutch.
Andrew S. Gray.
Francis Barritt Hills.
Bertram George Kelly.
Max Levinger
Reginald Lacey Lunt.
Joseph Makin.
Ernest Gordon Dewar Mathews.
Thomas Green Richardson.
Stewart Augustus Sillem.
Sidney Lyon Smith.
Norman West.
James W. Wonfor.

Students.

Keith Bradbury Barlow.
Jesse Haigh Baxter.
Henry Morrison Bremner.
Joseph Griffiths Clare.
Wm. Anselm Coates.
Geo. Mather Craig.
Thomas Russell Davidson.
Bernard Palmer Fisher Deane.
Sydney George Frost.
George Rupert Griffin.
Owen Lewis Ilbert.
William Dallas Long Jupp.
Edmund Weston Kay.
Sidney Charles Kefford.
W. H. Lowe.
Frederick Hill Masters.
Joseph Meech.
Walter Reginald Mickelwright.
Stanley Melbourne Mohr.
Harold W. Purle.
Henry Withers Refford.
Harold Wm. Townend Sabine.
Nils Percy Patrik Sandberg.
James Benjamin Spellar.
Alexander Thomson.
Francis W. Wilson.

The Three Hundred and Eighty-seventh Ordinary General Meeting of the Institution was held at the Institution of Civil Engineers, Great George Street, Westminster, on Thursday evening, February 5th, 1903, Mr. JAMES SWINBURNE, President, in the chair.

The minutes of the Ordinary General Meeting held on January 22nd, 1903, were by permission taken as read, and signed by the President.

The names of new candidates for election into the Institution were also taken as read, and it was ordered that these names should be suspended.

The following list of transfers was published as having been approved by the Council :—

From the class of Associate Members to that of Members—

Thomas Hesketh.

From the class of Associates to that of Members—

Walter Cullingford Goodchild. | Hugh Lionel Randolph.

From the class of Associates to that of Associate Members—

David Armitage.	Alexander Lindsay.
Frederick Rains Batty.	Jas. Walker Ormiston (Major R.A.)
Arthur Christian Gibbons.	Geo. Ernest Murray Stone.
Archibald John Howard.	Geo. Stamp Taylor.
Wm. Noel York King.	Lancelot Wm. Wild.

From the class of Students to that of Associates—

Benjamin Adair Malcolm Boyce.

Messrs. I. W. Chubb and C. W. Fourniss were appointed scrutineers of the ballot for the election of new members.

Donations to the *Library* were announced as having been received since the last meeting from H. M. Patent Office, and Mr. Charles Bright, Member; to the *Building Fund* from Messrs. G. W. Bousfield, M. B. Byng, H. C. Channon. E. Fawssett, S. E. Glendenning, R. J. Hatton. H. E. Herring, E. Pink, R. O. Ritchie, J. Shaw, H. D. Symons, J. A. Troughton, G. Walsh; and to the *Benevolent Fund* from Messrs. G. W. Bousfield and J. G. Wilson, to whom the thanks of the meeting were duly accorded.

The President.

The PRESIDENT: We will now proceed with the adjourned discussion on the Metric System. You will remember that Sir Frederick Bramwell opened for the English system, and he would now like to add a little to what he said on the last occasion.

Sir Fredk. Bramwell

Sir FREDERICK BRAMWELL F.R.S.: I wish to thank Mr. Siemens for having endeavoured to call my attention to a mistake into which I had fallen. His observations were perfectly pertinent to the occasion. I imagined that those tremendous penalties in the Acts were penalties invented by the advocates of the metric system to get it enforced. He tried to call my attention to the fact they were a mere repetition of the penalties existing in the Acts which enforce the English system. All I can say about it is, that although they sound equally dreadful in both cases, to my mind under the English system there was so little likelihood of punishment that the penalties, dreadful as they were, were not likely to be inflicted: whereas, if the same penalties are enforced in regard to the compulsory introduction of the metric system, infringement and punishment will, I expect, be very great. Having said that much I wish to call your attention to one thing, namely, that this metric system is being forced upon us practically by the French nation. It does not seem to me becoming to such a nation to force the metric system, or anything else relating to numeration, upon others. Just fancy! to the present day they cannot tell you 99 in words without resorting to the childish expedient of four 20's, one 10, and a 9, and those are the people who are going to try to make the whole world go right!

The only other thing I have to say is to ask Mr. Siemens, when he is consulted about the framing of the new Bill, to put in a "Conscientious Objector" clause, as they did in the Vaccination Act.

Mr. Dowson.

Mr. J. EMERSON DOWSON: I think that in a serious discussion such as this is, it is important that we should have clearly in our minds why we are comparing the metric weights and measures with those of the Imperial system which is now in use. I hope you will agree with me that it is not merely to contrast their relative merits, but, above all, to see how far we can and should adopt an International system—a universal language, so to speak, of weights and measures. With these few preliminary remarks I will, not only for myself, but for the Decimal Association whom I represent, endeavour to meet some of the points which Sir Frederick Bramwell has brought before us.

In the first place, with regard to Napoleon. No one can question the military genius of the great soldier-emperor, and he may have been an authority in his time on the subject of weights and measures; but whether he was so or not, I can hardly suppose that our engineers and manufacturers of to-day will be much influenced by what Napoleon may have said on the subject some eighty years ago. Since then our commercial relations with other countries have changed greatly, and whether we like it or not, the plain fact remains that after France had proved that the metric system of weights and measures was practical and good, it was adopted by Austria, Belgium, Germany, Greece, Holland, Italy, Norway and Sweden, Portugal, Spain, and Switzerland; in fact, by all the European countries except Great Britain and Russia. It has also been adopted throughout South America and in Japan. As regards Mr. Beresford-Hope, Sir Frederick Bramwell advised us all to read the speech made by this Member of Parliament some forty years ago against the metric system, and I for one have done so. He said:

Mr. Dowson. "Only imagine an honest housewife going into a shop and asking for a decigramme of pepper, and a dekagramme of tea." I reply that in the ordinary affairs of life no one wants to buy the tenth part of a gramme of pepper, or of any other commodity. Also the term dekagramme is seldom if ever used, and the purchaser should ask for ten grammes and not a dekagramme of whatever he wants. Mr. Beresford-Hope also said: "If a housewife has to cut up a loaf for her family she divides it into 2, into 4, into 8, or into 16 parts." I don't think this is the usual way of dealing with the domestic loaf, but, after all, what has it to do with the practical adoption of a decimal system for general purposes, seeing that the binary divisions will always be used, and should be used as far as possible, whatever may be the system of weights and measures. Mr. Beresford-Hope, however, went further, and said: "Supposing the loaf to weigh originally a pound, each of these sixteen divisions comes to an ounce." But one might reply that, supposing the housewife had to divide the loaf into five or ten parts of equal weight, she could not do so with the ordinary household weights of pounds and ounces, whereas in the metric system it would be quite easy. The fact is that no system is the best under all circumstances, and from a practical point of view we have to select that which presents the greatest number of advantages. As to foreign trade, Sir Frederick Bramwell admits that our manufacturers and merchants must be handicapped in their dealings with metric countries, if they do not make and sell on the metric basis. But to do this under existing conditions they must use one set of weights and measures for their foreign trade and another for the home trade. There is not time for me to consider all the losses and inconveniences this entails, but I think you will agree with me that a dual system has many obvious drawbacks, and cannot be right. So far as I can judge, the remedy is to have one international system for all purposes.

Decimals.—The importance of always dividing without a remainder has been greatly overrated, and actually all scientific men of the present day use the metric weights and measures and no others. It is also a mistake to suppose that if a decimal system were generally adopted, vulgar fractions could not, or would not, be used. Decimals are not upheld as exclusively right, but rather as preeminently convenient; and when in certain cases it is quicker or more accurate to use vulgar fractions, undoubtedly they should be used. This is the common practice in all metric countries.

It is also worth noting that at the present day a *decimal* system of coinage has been adopted by *every civilised country in the world*, except Great Britain and some of her Dependencies. It is, moreover, a fact that in no single instance has any country given up the decimal system after once adopting it.

Decimal Point.—On architectural and engineering drawings it is now usual to write all dimensions under one metre in millimetres, *as whole numbers*, without any decimal point. They are then added together to get the main dimensions, and, if the total exceeds one metre, the metres and millimetres are separated by a mere stroke of the pen. Compared with feet and inches, and fractions of inches, the

operation is not only more simple, but there is less risk of mistakes being made. Mr. Dowson.

In makers' price lists of pipes, steam fittings, etc., it is usual to give all the dimensions in millimetres only, without a single decimal point.

In this country a dot is generally used to denote the decimal point, but on the Continent a comma is used, and I think the latter is safer, as it is larger and more conspicuous.

Nomenclature.—I agree with Sir Frederick Bramwell that a long list of composite Greek and Latin names is undesirable, but in actual practice only a few are used, even in France, where the system originated. We may take Germany as representing practical up-to-date teaching, and in the primary schools of that country it is usual to teach the units and sub-multiples, and only a few multiples. For all practical purposes we need only the metre, divided into centimetres and millimetres; the litre divided into decilitres; and the kilogramme divided into 1,000 grammes. There is really no need of any tables. The metre can be squared for measures of surface, or cubed for measures of bulk or volume, just as yards or feet are squared or cubed.

If preferred, the word *pound* can be used for half a kilogramme, just as the *livre* is used in France. The mere name is comparatively unimportant provided the *value* is understood in grammes. The names centimetre and millimetre are no more difficult to understand or remember than such words as subtraction, multiplication, telegram, etc.

[*Communicated after the meeting:—Relations of Units.*—Sir F. Bramwell said little about these, but they are important features of the metric system, and are of great value. We know, for instance, that one cubic centimetre of water, at its maximum density, weighs one gramme; that 1,000 cubic centimetres, or one litre, of water weigh 1,000 grammes, or one kilogramme. Hence one cubic metre of water contains 1,000 litres, and weighs 1,000 kilogrammes, or one (metric) ton.

As the density or specific gravity of a substance is its weight in relation to that of water, and as the weight of water contained in any metric measure of volume is known, it follows that the weight of any substance can easily be found when its bulk in terms of the metre is known. We have only to multiply the volume or bulk of the substance in question into its specific gravity, and we shall know its weight. Or, conversely, if we know the weight of any substance, we can easily find its volume by dividing the weight by the specific gravity.

It is certainly a gain to have a uniform *volume-unit* of water, as in the metric system; for all calculations of volume and weight of other substances are then simple and rational. In our present system the volume-unit is sometimes a gallon, sometimes a cubic foot, and sometimes a cubic inch, and there is no uniform basis to assist the mind in comparing various substances.

Mental Arithmetic.—Sir F. Bramwell has very properly urged the desirability of practising mental arithmetic, but thinks that with the metric system this cannot be done. I venture to say that if he will be good enough to look over some of the French and German books of

Mr. Dowson. arithmetic of to-day, and will ascertain what is actually done in the primary schools of those countries, he will find that attention is given to this, and that mental gymnastics not only are possible, but are practised, with the metric system.

Short Cuts.—I can readily understand that after his long and varied experience, Sir F. Bramwell is loth to give up the short cuts and *aides mémoire*, which he has found it necessary or useful to adopt in connection with our present weights and measures. With the metric system short cuts are seldom, if ever, needed, and as Sir Henry Roscoe once remarked on this subject, "We do not want a short cut if the road is straight." [1]]

There is much more I could say on this interesting subject of weights and measures, but time forbids. In conclusion I would remind you that the conditions of life in all civilised countries have altered greatly during the last quarter of a century. Each country has developed its resources and manufacturing powers enormously; steam and electricity have done wonders; there are much greater facilities for travelling; and there is much greater intercourse between nations. This will not diminish, it will increase; and to save our time, and to help us in our dealings with foreigners, surely it is worth while to put up with some temporary trouble and inconvenience, to rid ourselves of our present complicated weights and measures, and to adopt those which have been adopted irrevocably in nearly all civilised countries.

Let us remember also that we have to think of our Colonies and Dependencies. As a matter of fact most of them are really anxious to adopt the metric system, and are now looking to the Mother Country to take the lead. This is no mere opinion on my part. The subject was discussed by the Colonial Premiers at their Conference in London last year, and they passed the following Resolution :—

> "That it is advisable to adopt the metric system of weights and measures for use within the Empire, and the Prime Ministers urge the Governments represented at this Conference to give consideration to the question of its early adoption."

Actually we are within measurable distance of getting an international system for all purposes if we will but have it. Men of science have adopted it already, and I ask you, Why should not engineers and manufacturers do the same?

Mr. Parker. Mr. T. Parker: Most of what we hear is usually aimed at the metric system; we do not find criticism of the system. When we look at the metric system as a whole we think of two quantities. The metric system of weights and measures consists, shortly, of a volume measure based upon the measurement of length, and of a weight unit which is the weight of that volume of water, the unit of specific gravity and the thermal unit being based on certain properties of water. We thus have a connection between the mechanical, electrical, and physical units, and so science has in this system a sort of handmaiden without which it is impossible to proceed. We cannot remain

[1] The Communicated portion of Mr. Dowson's remarks ends here.—Ed.

Mr. Parker.

TABLE I.

Relative Dimensions of the Metre and Derived Units.

Metre Unit.	Cubic Metre.	Metre Ton.
Decimetre $= \frac{1}{10}$	Litre $= \frac{1}{1{,}000}$	Kilogram $= \frac{1}{1{,}000}$
Centimetre $= \frac{1}{100}$	Millilitre or Cubic Centimetre $= \frac{1}{1{,}000{,}000}$	Gram $= \frac{1}{1{,}000{,}000}$
Millimetre $= \frac{1}{1{,}000}$	Cubic Millimetre $= \frac{1}{1{,}000{,}000{,}000}$	Milligram $= \frac{1}{1{,}000{,}000{,}000}$

NOTE.—$\frac{1}{2}$ Millimetre = nearly $\frac{1}{50}$ inch; $\frac{1}{4}$ Millimetre = nearly $\frac{1}{100}$ inch; $\frac{1}{10}$ Millimetre = nearly $\frac{1}{250}$ inch.

TABLE II.

Inch Units.

Inch Unit.	Cubic Inch.	Cubic Inch of Water Weight.
Mill. $= \frac{1}{1{,}000}$	Mill. Volume $= \frac{1}{3}$ Minim $= \frac{1}{1{,}000}$	Mill. Weight $= \frac{1}{4}$ Grain $= \frac{1}{1{,}000}$

NOTE.

960,000	Mill.	=	80 feet = 960 inches.
3·6	Mill. volume	=	1 minim.
1	Mill. weight	=	·252 grain.
62,000	Weight units	=	1 ton.
25	"	=	·9 lb.
25	Cubic inches	=	·09 gallon
10,000	" "	=	36 "
73,000	Inches	=	1 sea mile.
61	Mill. volumes	=	1 cubic centimetre.
61	Cubic inches	=	1 litre.
61	Mill. weights	=	1 gram.
61	Inch weights	=	1 kilogram.
62,000	Inch weights	=	1 ton.

Government Survey—

25 inches	=	1 mile.
1 square inch	=	1 acre.

The ratio of inch units to metre units of weight, or volume, is 5 (inch) units are equal to 82 grammes or cubic centimetres correct to $\frac{1}{1{,}30}$.

$50^3 = 2{\cdot}0125$ tons.
$25^3 = {\cdot}2514$ tons ($\frac{1}{4}$ ton + $\frac{1}{160}$).

Mr. Parker. where we are. Now, if we go on we must, according to the present verdict, accept the metric system in its entirety.

After using the metric system for thirty years, and after having devoted some four years of critical study to it, I say that the units of that system are entirely unsatisfactory, and imperfect. I have carefully read the whole of the information given before the American Commission; I have heard what Sir Frederick Bramwell has said, and I have read the Commission's reports in this country, and all else I could find that has been written upon the subject. I have discovered no objection made to the metric system of weights and measures, but I have found the objections to apply wholly to the dimensions and ratios of the units used with the metric system. As Sir Frederick Bramwell very wisely pointed out, we are bound to decimals by the units of the metric system. The form in which the question presented itself to my mind is set out in Table I. (p. 301). Those dimensions of the units of the metric system mean the entire destruction of the whole of the measuring systems of the world, excepting that of those who introduced it, and they had to introduce it to the destruction of their own. What do we find in looking over the evidence of America? We find men coming forward, representing large manufacturers in the country, saying that they do not want it; we find such men as the Chief Constructor of the Navy of America saying, "We do not want it." But they did not go into the matter and see if it could be improved. The only way in which you can improve the units of the metric system is by altering the length of the metre, and they did not do that for Whitworth, nor will they do so for us to-day. But you cannot alter the units so as to retain the metre; they are fixed by the length of the metre; you have to put up with them in their present form. They are a cumbersome lot; they begin by initiating fractions, fractions of fractions, cubes of fractions, ½ and ¼; and even then you do not get what we have in our ordinary inch and 1,000th. I was led to make a number of exploiting figures and experiments, to try to find out where we could amend the metric unit, and came to the conclusion, that if we are to have a perfect set of units with the metric system there is only one length that can give it, and that is the inch length, and there is no improvement possible upon that. I have set that out on Table No. II., and you can compare it with Table I. You will see that we want but one set of units. I have put below the inch units, the fraction of a 1,000—namely, the mill., the mill. weight, and mill. volume. You will see that those units are perfectly equal whether you multiply them or divide them to any extent: they always remain in ratio, and they do not confine you in any way to decimal arithmetic. You can employ all the arithmetic you are now using, and you may pass to the metric system if you permit the inch to be used as a unit to-morrow, and you will then have all the advantages of that system. You can improve the metric system, and you can improve the new metre units off the face of the earth, by simply sanctioning the use of the inch as a unit of length, and legalising the weight of a cubic inch of water as a unit of weight, and meet no objection. Four or five years ago I should have been as willing as anybody to crush the measures of England for the supposed

benefit of the metric system; but to-day I say that if you do so you will disgrace yourselves for all time. You are all asked now to adopt the metric system in your country, and you are going to do it at the expense of a social revolution, and after an expenditure of millions of money, and in the end you will only get an imperfect thing whilst you could have had a perfect thing. Here it is already established: simply legalise the weight of an inch of water, permit the use of the inch as a primary unit of the metric system, and you have all that you can get by the metre and a great deal more. You simplify the units, and make them perfect, and you disturb nothing. I do not advocate suppressing the metre; but from what we hear of our American friends—I hope there are some of them here—they always scrap anything when they find something better, and I shall expect that they will at once scrap the metre and all that belongs to it, and adopt the inch. Mr. Parker.

I do not want to trouble you with history—we have had enough already—nor with cross-calculations, because we know all about them. I will try to inform those gentlemen in the House of Commons who will be called upon to decide for this country what they will do in the matter of weights and measures, as to the virtues of the inch, and then I shall be conscience-clear. They are men who will, I trust, look after the economic policy of the question, and we shall be permitted to use our venerable old inch in its proper place and character, and get a simple and perfect set of units for the metric system. It is impossible to enforce the metre. It would be a calamity to do so.

Sir ANDREW NOBLE, F.R.S.: I find myself placed in rather a peculiar position, for I find myself opposed to a man for whom I have the greatest reverence—I mean my friend Sir Frederick Bramwell. But we agree upon so very many points that I think we may agree to differ upon this one point, or rather I should say two, for the metric system is mixed up with the decimal system: both are involved, and I think the decimal system is even more attacked than the metric. As regards the decimal system, I must say I think it a scandal to this country that we have never had our pound sterling (£) decimalised. At present every silver coin we have is an exact decimal of a pound: the only thing we want is the alteration of making a shilling fifty farthings instead of forty-eight. In that case every subdivision of a pound would be represented by three decimals, whereas at present, if you get 19s. 11¾d., you have six figures. The difference in rapidity of calculation is enormous, to say nothing of the power of using very simple calculating machines. I mention this as a point was made in regard to reducing the number of figures. Sir Andrew Noble.

I must say, having had a great deal to do with foreign countries, I find a very great inconvenience in our English system of weights and measures of all sorts. Some of our measures, for example the thermometer, are founded upon errors, and our weights are entirely haphazard. Taking our weights, the only common weight that I know of is the grain. Our ounces are different, and our pounds are different. I daresay all of you have heard the question as to which is the heavier, a pound of gold or a pound of feathers, and I myself have heard the

Sir Andrew Noble.

whole of the possible answers given to the question. The difficulties that are placed in the way of any one, who, like myself, has to compare large numbers of foreign weights and measures are almost insuperable. I recollect the late Professor Hoffman saying to me once when pointing out the inconvenience of our measures, that if you wanted to make any considerable induction, the observations of philosophers or men of science in one country were a sealed book to those in another country. Since he said that, there has been a great advance in the use of the metric system, and I need not say that almost every scientific society, with which I am acquainted, refuses to receive papers that do not use the metric system.

The metric system is, in my opinion, a most carefully thought out and perfect one. It is based upon one single element—that of length. The metre is taken, I think, at the 10,000,000th part of the quadrant of the great circle of Longitude passing through Paris. It is prolonged by decimal multiplication, 10, 100, 1,000, etc., and for these are used the Greek prefix. For subdivision they use the Latin. If you take the smallest weight, the gramme, that is the weight of water in a centimetre cube; the kilogramme is a decimetre cube, and the ton is the metre cube. Observe that it has these great advantages. You know the weight of a ton is a metre cube of water. If you know the specific gravity of any metal or other material you are able at once to give the weights in tons and decimal parts. Then the metre and its subdivisions satisfy the superficial measurement, and the one great advantage the metric system has, is that if we adopt it we have with that a uniformity of measures for all countries. I need not say it is hopeless to get other nations to adopt our system, and nobody can dispute the advantage it would be to us if there was but one system of weights and measures throughout the world. I will not recall to your minds the number of nations that have adopted the metric system, but I will say that in my opinion the metric system ought to be made compulsory within a certain number of years. The question is how to do that with the least inconvenience.

A most admirable proposition was made by my friend Professor Johnstone Stoney, whereby we might alter our weights and measures almost infinitesimally, and, at the same time, keep for those who prefer it the same nomenclature. Professor Johnstone Stoney in his paper proposed that the new yard should be exactly 9 decimetres. Most of us I daresay when, for rough calculations, we consider the centimetre, call it 0·4 in., and the inch 2·5 c.m. The alteration is very slight in making the inch exactly 2·5 c.m., and in that case the yard would be exactly ·9 of a metre and would only be altered by an exceedingly small fraction, about 1 per cent. of its length: the same would apply to the foot and the inch. You might keep for a certain number of years, or altogether if you like, the old nomenclature. The inch, as you know, would then be 25 millimetres; all of you have seen an inch divided into 100; it would only mean that the inch would be altered by 100th of its length, and there could be no great inconvenience in that. Then I think Professor Johnstone Stoney proposed that the mile should be 1,600 metres. That means that our mile would differ from our present

measure by only about the breadth of a narrow lane, and no inconvenience would result. In regard to weights, the new pound (lb.) would be $4\frac{1}{2}$ hektogrammes exactly, which would differ from our present pound by under 1 per cent. If these systems were adopted, they might prevent the inconvenience to which some of the speakers have alluded, that is to say, there would be no rough break in our ideas, and I do not think the public would suffer much. Anyhow, I desire, in conclusion, to express my opinion that sooner or later the metric system must be adopted, and I would add that I think it ought to be as soon as possible, and that the change should be effected with as little inconvenience to the public as possible. Sir Andrew Noble.

Mr. LESLIE S. ROBERTSON: I did not intend to speak to-night for more reasons than one, but as you have called upon me I will add a word or two on the practical side of the question. It has been my privilege to superintend work in countries where the metric system is in use, and also in this country. I had, after following very carefully the construction of torpedo boats in this country in a torpedo-boat works not very far from London, to go over to France and build similar boats and boilers for the French Government in one of the leading works in France. One of the difficulties we had to encounter was this. An English piston-rod would be to some even dimension, say 2 inches, but when we got abroad nobody would think of making the piston-rod 50·8 mm. Therefore the whole of the drawings had to be redrawn, and what was our 2-in. rod here was not our 2-in. rod there. Then we had another very serious inconvenience, namely, in connection with the screw threads. Our British threads are stronger and deeper than the metric threads; and when certain classes of work are arranged for British threads they do not come in comfortably, to say the least of it, on the metric system. It is felt in France and elsewhere, I think, too, that the metric threads are not altogether satisfactory. This was emphasised by another practical experience. When I was abroad last year with one of the Government Commissions studying the question of locomotives, I made careful inquiries and found that, in the most up-to-date German works, in fact, practically in every works that we visited, they were using our Whitworth thread and not the metric thread. Mr. Robertson.

I do not know if there is any definite proposition before the meeting. We all admit the advantages of the metric system, and they are many, but it is no good merely discussing the question from a general point of view. The metric system is permissible in this country; anybody can use it who wants to. The question is whether this meeting thinks it justifiable to urge upon the Government, which is the only body that can take any action in the matter, that they should make the metric system compulsory. That is a very drastic step to take. Perhaps there will be some definite resolution before the meeting prior to its close, but I venture to think that the meeting will have to consider very carefully before they come to a vote on the question as to whether they are in favour of making the metric system compulsory in this country. It is now legal, as I said before, and anybody can use it who wishes to do so, but it is a very open

Mr. Robertson. question whether public opinion is sufficiently ripe for the metric system to be compulsorily forced on the country by the Government.

Dr. Stoney. Dr. JOHNSTONE STONEY, F.R.S.: Sir Andrew Noble has already spoken of the system I have proposed, and I do not think it necessary for me to enter on any of the points that he has referred to. I think myself justified in claiming that Sir Andrew Noble's opinion ought to carry special weight, both with the people of England and in Parliament, on account of his unexcelled experience and acquaintance with every aspect of the question in debate, and because the opinion he has expressed here to-night is an opinion formed with great deliberation. He has here reiterated, after two and a half years' further consideration, the same judgment as he expressed in 1900, when my proposal was first put forward. Our present position in reference to weights and measures is simply this, that by recent legislation we have been relieved from being publicly punished, if we buy or sell by metric weights. There have been three Metric Acts, one the Act of 1864, which was intended to render the system permissible, but which failed in that object in consequence of the legal difficulties that were raised. So matters remained for a number of years, till 1878, when for the second time an Act was passed dealing with the use of metric weights in this country. It supplied the omissions in the Act of 1864, but while permitting the use of metric measures for other purposes, it forbade their use in buying and selling. The result of that state of things was, that metric weights came into use for all scientific purposes in this country, but they could not be used by any chemist who kept a shop, and the Act compelled chemists and druggists to continue the use of the bad system known as Apothecaries weights and measures. In 1896 the Government introduced a Bill to get rid of the restriction introduced into the Act of 1878, and they appended to the Bill they introduced in that year a body of equivalents similar to, and equally cumbersome with, those under the Acts of 1864 and 1878. The Bill was withdrawn in that session, but in the next session it was passed without the objectionable tables, and improved tables were, in 1898, issued by an Order in Council. These are now the tables of equivalents that have legal force in this country.

Since then deputations have waited upon the Government; and both Mr. Balfour and Mr. Ritchie in answer to these deputations said that the next step to be taken was by the people, and not by Parliament. They were under the impression, as the last speaker was, that the late Bill did all that was necessary to render it permissible to use metric weights and measures. All that the Bill does is that it prevents a person who uses them from being publicly punished. That is not sufficient. It is necessary to make it possible for them to use them without incurring large trade losses. The deputation recommended that the metric system should be introduced compulsorily within two years. My own impression is that the duty of our governors is rather to lead the people than to drive them, and I submitted the proposal referred to by Sir Andrew Noble, suggesting that the best legislation to introduce would be to alter our standards of length and weight without altering the relations in which the different sub-divisions of the

Dr. Stoney.

Imperial system stand to one another—altering them by excessively small quantities, which will suffice to bring them into simple relation with the metric system. If this proposal were carried out it would be possible for work to be begun in one shop where Imperial measures are used, and continued in another shop where metrical measures are used, and nearly all the other practical difficulties which prevent business men from adopting metric measures would be got over. I am myself persuaded that we may wait for fifty years if the only policy suggested to Parliament is to pass a Bill making the use of Imperial measures illegal. I would claim that persons occupying the attitude of Sir Frederick Bramwell should accept with readiness my proposal. He has expressed his desire that the two systems should be tried, leaving whichever is the better to win the day; and the way to do that is to bring them into such relation as to make the use of either system possible. All the advantages which he supposes attach to the existing system would be preserved if this proposal were carried out; and we might all look to the future with confidence, including those of us who hold, as I do and as Sir John Herschel did, that the people of England, if enabled practically to try both systems, will prefer that one of which the divisions are brought into the most natural relation to our system of numeration, and of which the weights and measures of capacity are connected in a rational way with the measures of length.

The President.

The PRESIDENT: I will now read a letter that I have received from Lord Kelvin:—

Lord Kelvin.

Lord KELVIN (*communicated*): Will you tell the meeting to-morrow that I am very sorry I cannot be present to hear Sir Frederick Bramwell, and to endeavour to convince him that the universal adoption of the French metrical system by electrical engineers and engineers of all classes, and common-sense people throughout the country, and in all saleshops and workshops and factories, will be a great blessing to every individual person concerned, including home and colonial British subjects and the whole rest of the world.

Sir William Preece.

Sir WILLIAM PREECE, F.R.S.: On this particular subject the line that I take up is this. It is no new fad of mine, for I find that in March, 1853, exactly fifty years ago, I wrote a paper on the advantages of the decimal and the metrical system, and my fifty years' experience has been an addition to the strength of the feeling I had then and have now, that there is a great deal in the metrical system, but a great deal more in the decimal system. The two are totally different: you must deal with each on its own merits. First of all, I say that if the metric system or the decimal system is to be introduced, it must be because there is a necessity for it. Either there is a necessity for it or there is not. If there is not, no compulsory Act of Parliament, no resolution of this Institution will force on this country a thing that is not wanted. If it is wanted it does not require an Act of Parliament to enforce it. Necessity, commerce, the demands of trade, the business of this country, will introduce a system, decimal or metrical, into the habits and customs of our workshops.

Our system of weights and measures is, in spite of Sir Frederick Bramwell, execrable. Why, gentlemen, there are 154 distinct units of

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length to be found in different parts of this country. I would like to read the list through, if I had it: it is in an appendix to a paper published by the Society of Arts. But think of 154 units of length: there are the hand, the span, the cubit, the foot, the yard, the ell—I could go on for ten minutes if you would allow me—but I will stop! We only want one real, good unit of length; in the same way we only want one good unit of mass or weight, and of volume, and everything that is required. Mr. Parker has started a new hare. He has based a system on the inch, and he says the inch cannot be improved. To a certain extent I agree with him, but I go further, and I say, "Cannot be made worse." I asked him just now, What is an inch? He said he had gone back to the period of the Saxon kings, and he found that Edgar had introduced the inch. [Mr. Parker: Yes, he kept it at Winchester.] Let him go a little further, and what will he find? He will find that the inch is three barley-corns in a row, picked from the centre of the ear of corn—and that is our British inch! Now if that inch were a scientific inch, it would not be a bad system of units. Take Professor Johnstone Stoney's inch: it is much better than three barley-corns.

I want to urge that, in the first instance, there is no use attempting to change our units unless there is a necessity for it. In the second place, if there is a necessity for it, and I believe there is, the whole trade of the world involves the use of a uniform system of units, and that system must be, with our present knowledge, based on the metric system. Now with regard to the use of the metrical system. We hear from Sir Andrew Noble that it is introduced in the Elswick Works. I know from personal experience that it has been used at Willans & Robinson at Rugby, it is used by Siemens, it is used by Greenwood & Batley at Leeds, it is used by the Shropshire Iron Company at Wellington, and indeed I do not know by how many other places. Is there any single electrical engineer in this room who does not use the metrical system? I have been a member of the Committee of Standards of the British Association for over a quarter of a century, and we have introduced the c.g.s. system of units, which is purely metrical. Is there a man in this room who has found any difficulty in applying it? We have had twice to change the value of the ohm: has it caused any difficulty or trouble? On the contrary, throughout the whole world, in every country without exception, the metrical system has been universally employed. I am glad to see that even my friend Mr. Parker, with his three barley-corns, has gone so far as to meet the metrical system half-way by introducing what, after all, is the half-mile post to the ultimate goal, the decimal system. I say if we make any change at all, it must be the whole metrical system. I do not say there is a necessity for it, but I believe there is; and I do say that the time is not very far distant when we shall be forced by our trade and by our commerce to adopt either the metrical system in its entirety, or a very close approach to it.

Mr. Brough

Mr. Bennett H. Brough: I doubt whether Mr. Siemens was right in ascribing to James Watt the fundamental idea on which the metric system is based. Watt's ingenious idea of dividing the pound decimally was anticipated in 1620, by Edmund Gunter, who proposed a decimal

measure for land, the unit being the chain of 100 links. This convenient measure by which 10 square chains were made equal to an acre, is still in general use, and the conditions of land tenure are such as to render its displacement unlikely. The engineer for levelling uses the foot decimally divided. It is evident, therefore, that he is not averse, when necessary, to using decimal measures. The matter is entirely different if he is to be publically punished by fine or imprisonment if he uses anything else. The whole question is one of commercial expediency. It is quite possible that to the electrical engineer the compulsory change, which would undoubtedly be of inestimable advantage to Germany, would not be so disastrous as to the mechanical engineer, for the electrical engineer derives great benefit from German skill. Customs returns show that of electrical machinery the British imports from Germany are twenty times as great as the British exports to that empire. In other branches of engineering the change would be all to the advantage of Germany. The cost of compulsory change would be enormous. Every retail trader would require a new set of weights and measures (which German makers would have in stock to supply). Every gas pipe would have to be torn out of our houses. The Whitworth thread would have to go, all gauges and templates scrapped, and the working man fined or imprisoned if he drank his beer out of a pint pot. Even in Germany the change had been made with difficulty; and Rhenish inches, Lachter, Thalers and Groschen are still found in use. Mr. Brough.

In discussions of this kind, the metric advocates are apt to be led astray by their enthusiasm for a fantastic natural unit, which after all, as the meridian was inaccurately measured, is only an arbitrary one. Thus the author quoted by Sir W. Preece, who gave a long list of obsolete measures with a view to discrediting the Imperial system, omitted to mention that by the Act of 1878 the user of any of these measures was liable to a fine of £5, or of £10 for the second offence. Teachers of arithmetic are much to blame for the existing confusion, and for the retention of illegal measures. In the latest book on arithmetic, just published by the Cambridge University Press, the scholar is taught that in civilised countries, England being unfortunately an exception, coinage, weights and measures are arranged on a decimal plan. The author does not tell us that Great Britain, the British Colonies and Dependencies, the United States and Russia, where the metric system is not used, represent 40 per cent. of the world's population. It would be ideal if all nations spoke Volapük and used the metric system. But it is doubtful whether the uniformity would compensate for a change that would forbid the use of division by continued bisection, destroy our standards, and render our technical literature useless.

Sir JOHN WOLFE BARRY, F.R.S.: In rising to say a word in criticism, both of the metrical system and decimal system, I feel that one is somewhat like the man who was accused of speaking disrespectfully of the equator, because really one has heard so much said, and so weightily said, in favour of the metrical and the decimal system, that it requires some courage to raise one's voice on the other side of the question. I am bold enough however to say that I am averse to the Sir John Wolfe Barry.

Sir John Wolfe Barry. metre as a unit, and that I am averse to the decimal system for many purposes of calculation. I do not mean to say that both may not be useful to many people, but I am perfectly certain that they are by no means desirable for everybody. I do not wish for one moment to defend the system of weights and measures in this country. They are complicated and unscientific, there is no doubt, but that has nothing to do with the question of adopting either the decimal system or the metrical system. Mr. Brough has said that the proportion of people who do not use the metrical or decimal system is 40 per cent. of the whole of the population of the globe. I have been informed, but I will not vouch for its truth, that they are in excess of half. [Mr. ALEX. SIEMENS: With the Chinese ?] No, not the Chinese—we do not really know what system they use in China; so we will leave China out of the question. But when we are told that we must of necessity come to the metrical system because the Latin nations, helped up by Germany, have adopted it, I would like to recall the time when we were similarly told that everybody must learn French or they would not be able to communicate with people on the Continent. What has been the result? English is far more universally used than any other language in the world. Our object ought to be to get the best system, and to see that we are satisfied that it is the best system. If it be the best system, I hold that Great Britain, with her Colonies and Dependencies and the United States, will set the tune, and that other nations will follow. Therefore, let us see what is the best, and not rush at the metrical or decimal system, because we are told that a number of people who, with the exception of their latest proselyte, Germany, are not great commercial peoples, have adopted the metrical system.

I have worked in times past a good deal with my hands, and I am certain that the metre is too large a unit; it is not convenient. The foot is infinitely more convenient for all work in which I was engaged. Again I hold most strongly that the possibilities of division of 12 are far more convenient for practical men than any system based on 10. I spent also a great deal of my time once in what is called quantity measurements, where we are continually dealing with complicated fractions —2 ft. 4 in., 12 ft. 8½ in., 5 ft. 11 in., and all that description of dimensions, both in computing areas and cubes; and I know that the fact that the foot is divided into 12, makes rapid computation far more easy than any division into 10.

When you can divide your unit, first of all by 2, then by 3, then by 4, then by 6, and then by 8 for 1½ in., I hold that a duodecimal system of measurement and computation is far and away more convenient for rapid practical work than any decimal system.

We talk about international trade. What is our position in regard to international trade, and how much do we export into all these protected countries who have adopted the metrical system? Why do we want to make it easy for continental nations to supply our home and colonial markets when we get no reciprocity whatever? I am not saying that that is a reason in itself against the decimal system or the metrical system, or in favour of the duodecimal system, but I merely allude to it because those who so ardently advocate the metrical and the decimal

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system say that it is necessary for our international trade. I do not think it is necessary for international trade in the sense in which that is understood. Some previous speaker said with great truth that it will make it uncommonly easy for our friends who are represented by Mr. Siemens here, or who are at any rate represented by his family, to compete with us in every market in the world. I have no doubt it may do so, but is that a reason for our getting rid of convenient units and adopting inconvenient units?

There is another point on which I wish to touch. What is to be done with the measures of time? Is the day to be divided into 20 hours instead of 24 hours? What is to be done with all the measurements of latitude and longitude? Are they to be all made decimal, and are our sailors to be forbidden to sound in fathoms?

But what is the reason for all this advocacy? And why make it compulsory, for that is what is really intended by its advocates? In 1895 it was made permissible; let those who want to use the metrical system or decimal system continue to use the metrical or decimal system, but it does seem to me perfectly ridiculous, in this year 1903, to think for one moment that Parliament would compulsorily enact the use of weights and measures which would be inconvenient to a very large proportion of the population and hugely costly. Why not, as Lord Melbourne said, leave it alone? Those people who have to supply countries which use the metrical system with girders and similar articles can use the metrical system. What more do they want? Both systems are useful, I readily admit that for scientific purposes; and very likely for electrical purposes, with which I am not so intimately acquainted, it may be exceedingly useful to use the metrical and decimal system. But why make it compulsory? We can get on very well as we are. I do not, however, suppose that a meeting like this is going to pass any resolution, because that is not our business. We are here simply for the purpose of discussing the question and exchanging ideas, and I should deprecate any other aspect of the subject.

We are told that by some very elaborate system we could in a state of transition make our present units fit the metrical units. That means that we shall have three systems at work. Can that be useful or practical?

I venture, in conclusion, to say that first of all any system which is divided by twelve is the most convenient thing for the working man. I believe I am right in saying that to this day in Paris, the very heart of a compulsory metrical system, the opticians' work is done by the old French inch, which is divided by twelve, and that the dozen is still used in France in many trades. I do not speak from want of experience in practical work, as I worked at the bench myself for a year and a half, and I have spent a great deal of time in the computation of measurements. I accordingly put before this meeting my strong opinion that the duodecimal system has advantages to which the decimal system can never attain, and that if you compulsorily adopt a decimal system you will absolutely destroy that mental arithmetic with which most of the people who have to do with measurements make with ease and rapidity almost all their more simple calculations. Therefore, as I said

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before, although I feel that perhaps one is speaking to many people who are convinced the other way, I raise my voice against any compulsory adoption of either the metrical or decimal system, although I firmly believe that both are useful in their proper places.

Mr. Tannett Walker.

Mr. F. W. TANNETT WALKER: I have come over two hundred miles for the purpose of speaking because I am a very strong believer and thinker on the subject. First of all, a word or two about the money. I am a good deal associated with Chambers of Commerce, and these Chambers of Commerce are almost universally very strong supporters of the decimal system. I am not. They do not seem to understand what they want, and none of them can agree as to what their money standard is to be. One gentleman proposed a half-sovereign, another gentleman suggested that it should be called a Victoria, and another recommended a florin. They recommend all sorts of computations, but none of them can agree. As long as they cannot agree, I think it is absolutely fatal for the good of the country that they should attempt to change the standard. People who cannot agree have no right to ask for change. England has many good assets. We have a very good Navy, a very good Army, and a very good reputation; and as far as I am concerned I believe that the best part of our reputation is due to the constancy and never-failing value of the sovereign. If any of you have known what it is to send your family into Germany and then have to pay the bill, you will find that when you get the bill for your three weeks' holiday and give them an Englishman's cheque—not in sovereigns—they will give you as an acknowledgment of the morality of that Englishman's cheque as much German money as will enable you to treat yourselves like a Duke or diamond mine owner that night at dinner. Do not let us tamper with the value of the sovereign.

With regard to the dimensions, the weights and measures, I absolutely agree with Sir John Wolfe Barry in what he said; in fact, I would go further. I personally, in the course of my business as an engineer, have a good deal to do with calculations, and I have the greatest horror of this decimal system. I will tell you a story which will point to what I mean, rightly or wrongly. A Chancellor of the Exchequer received a deputation on the subject of the decimal system. The deputation was composed chiefly of commercial men, who, although they knew very little whether they meant the decimal system or the metrical system, honestly believed in what they had to say. They proceeded to describe the advantages of the decimal system. He said, "Gentlemen, do not waste your time; I have devoted immense thought to this subject and am a convinced believer in the decimal system." But these gentlemen felt themselves obliged to say something, and they urged that they could put before him certain points which would strengthen his advocacy of their cause. "Oh, well," said the noble lord, "by all means put your views before me, but, remember, I am a convinced believer, after great thought, in the decimal system." The Chairman then explained fully in what way everything would be worked out with the decimal system. "Most interesting," said the Chancellor of the Exchequer, "but tell me what

are those beastly little black dots?" Now, gentlemen, that is my view. I fear those beastly little black dots. I have a greater fear that my draughtsman will put a black dot at a wrong place, than I have a fear that he will say that twice 7 makes 15. Therefore, I have the greatest confidence in the old system, which, like a man, carries its individuality upon its face. Mr. Tannett Walker.

The man who cannot look upon life as an equation is the man who always comes to grief, either financially or in some other way; and I prefer the person who makes his calculation in the form of the old-fashioned equation, which naturally results in a vulgar fraction. If a man has a mind which puts its calculations in the form of a vulgar fraction, he has something to look back upon and to check his thoughts by when he is making his calculations; but the man who begins with the figure 1 and a thousand noughts, and wonders whether he is to put the dot here or there, is more likely to get wrong than the man who puts his $\frac{13}{16}$ths in one place and his other figure elsewhere; it is a thousand to one, if he is only patient enough, that he will eliminate the $\frac{13}{16}$ths when he looks for it. When he has made his calculation he has a definite thing in front of him, and the vulgar fraction reminds him of what he was thinking about when he made his calculation.

I believe it would be very foolish for this country, with its continually decreasing trade with foreign countries—not decreasing because we are decreasing in our ability, but decreasing because foreign countries are increasing their powers of manufacture—I believe it would be very foolish, as Sir John Wolfe Barry said, for this country to copy these people merely for the sake of being in with every one. England has never been a nation that has worked on the line of always trying to square the public; we generally try to go on our own lines; and although we may be very old-fashioned, and very muddling, and blunder-headed, we generally come out at a reasonably good place when we have finished. I do hope that we shall pause, and that we shall all get to understand exactly what we do want—whether the unit to be used is to be the metre—that metre which was supposed to be a measure of the surface of the earth, but which has since been found to be incorrect. I do hope we shall pause before we build our future hopes of success on any imaginary dimensions that may have been settled by other countries. As long as we can persuade foreigners to buy our machinery made to those miserable inches and those miserable feet and those miserable twelfths and fifteenths and sixteenths, I hope we shall not alter our dimensions merely for the sake of being able to measure the shaft of our motor-car, which comes from France, in French dimensions.

Mr. J. N. SHOOLBRED: Sir John Wolfe Barry in his remarks went to the root of the question when he stated: that what we have to consider lies in the difference between the duodecimal and the decimal systems. I cannot think that the duodecimal system, divided in the way in which Sir John gave us an illustration, is in any way simpler than the decimal system. My experience in France and in other Continental countries, as well as at home, during many years, leads me to think that the metric system is much the simpler of the two. Mr. Shoolbred.

Mr. Shoolbred.

Remarks have been made by Sir Frederick Bramwell, and others, as to the inconvenience which would be entailed, particularly in mechanical workshops, by the introduction of the additional measuring units of the metrical system. Sir Frederick illustrated this by reference to a paper by Mr. Coleman Sellers, presented, in 1880, to the American Society of Mechanical Engineers. Pointing out the extreme inconvenience, as well as cost, of the introduction of the metric system into machine shops in that country, that paper, Sir Frederick said, resulted in a recommendation to Congress not to introduce the metrical system. Sir Frederick, however, did not allude to the great change of opinion, which has taken place in the United States during the last twenty years, as is evidenced by the fact that Congress has at present before it a measure for the compulsory introduction of the metric system. Its introduction is to be gradual. In the first instance, the metric system there is to be imposed upon the Government Departments themselves, and in the second place, after a longer period, upon the general public; but no penalties whatever are attached to non-compliance therewith. Some arrangement of that kind would, in this country, relieve the compulsory introduction of this system of the drastic character which has been referred to. Furthermore, I am informed, apparently on good authority, that Mr. Sellers himself has not altogether abandoned the use of the metrical system in his own shops, as Sir Frederick Bramwell mentioned: perhaps Sir Frederick would ascertain whether this is so, or not.

With regard to the difficulties which have been mentioned by Sir Frederick Bramwell, Sir John Wolfe Barry, and others, as to the introduction of the metrical system, it appears to me that they are answered most effectively by the presence of such a large audience in this room. For the great, nay almost abnormal, increase of this Institution during the last twenty years is largely due to the fact that the C.G.S. units, which were first introduced by the British Association (and which mean practically the metric system), have since become the universal mode of electrical, and physical measurements, throughout all countries. So much so, that any person, in any country, may take up and understand the electrical and physical measures, in any text book, irrespective of the language in which it may be written. We ourselves, here, are therefore practically an example of what can be done, and that voluntarily, and without any compulsion, towards the introduction of the metric system.

Colonel Crompton.

Colonel R. E. B. CROMPTON, C.B.: A good deal of irrelevant matter has been brought into this discussion. Surely the first question for us to consider is whether a change to the metric system is possible, even if it is desirable. Although we all desire uniformity and simplification in our calculation of money, weights, and measures, we must remember that changing any linear standard affects the mechanical engineers of the world far more than any one else, and of these engineers America, England, and her Colonies constitute the majority. How then will the arguments that have been here used in favour of the metric system be received in America? Although Mr. Shoolbred has said that in America there are signs of a change of opinion in favour of the metric system, I

Colonel Crompton.

must emphatically contradict him. The state of American opinion is well shown from the recent discussions on this subject of papers read before the American Society of Mechanical Engineers which were well reported in *Engineering* of January 23, 1903, pages 104 to 107. The discussion on Mr. Halsey's paper on the metric system lasted two days and was followed by numerous letters from manufacturers, all showing that no one in America favoured the metric system. A very strong letter wholly condemning the metric system of linear measurement was read from Mr. Charles T. Porter, one of the most respected past-presidents of that Society. This letter deserves to be reprinted in full in this discussion.[1]

[1] The following is the letter referred to, as quoted by *Engineering* (1903, Vol. 75, No. 1934, pp. 106, 107) from *Engineering News* (December 25, 1902):—

"SIR,—'ABSURD!' Yes, that is the word with which the Committee of the American Society of Mechanical Engineers on the metric system fitly characterised and contemptuously dismissed the Bill, now before Congress, making our system of linear measurement illegal. That word was the necessary conclusion from the facts presented in the report of the Committee.

"The promoters of this measure were very properly excused on the ground of ignorance. If they had the least idea of what they were doing, of the unapproachable excellence of the system of linear measurement on which they were laying their hands—an excellence which is briefly outlined in the report of the Committee, but which can be realised only by those who are familiar with its use—their advocacy of this Bill would be without excuse, or rather it would be an act of which they would be incapable.

"To begin with, I arraign the metric system itself as absurd. The idea on which this system was founded was big and childish; one which no people except the French could ever have thought of. To them it seemed sublime. They would take for a unit $\frac{1}{10,000,000}$ quadrant of the meridian, or the distance on the earth's surface from the Equator to the Pole, and make this unit of a grand decimal system of measurement of everything on the earth and in the heavens; and from this they would derive a unit for another grand universal decimal system of weight. After the metre had been materialised in a metal bar, and this bar had been legally proclaimed to the world as the said universal unit, it was found to be too short, and the absurdity of this visionary fantasy stood exposed. The metre is merely an arbitrary unit, as any unit of measure or weight must necessarily be.

"This performance would be too ridiculous to notice were it not for these two facts. The metric system is still proclaimed to be the grand universal scientific system of weight and measure, and many merely theoretical minds, and I am sorry to say some practical mechanical minds also, in this country are dazzled by its brilliant pretensions. The fantastic foundation is also a key to the character of the system. We shall see that as a whole it is the product of the same merely theoretical and visionary minds.

"Secondly, the metric system is absurd in confounding together weights and measures, things which are entirely dissimilar and unrelated, and applying the same system of division to both. Universality was the hobby and the blunder of its schemers. Thus we have this result. Physicists deal with minute quantities, and do not measure, but only weigh. In the free exercise of their right to choice, they found the gram and its decimal divisions to be admirably adapted to their use; their work lying within the natural field of the decimal system. From this they jumped to the universal conclusion, which is not merely unscientific, but is senseless, that the metric system must be equally suited to everything: to things, large as well as small, and to measurements as well as to weight. But English-speaking people who measure do not agree with them. Therefore these people must be deprived of their right

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In Mr. Halsey's paper the following words occur:—

"The chief value of a standard lies in the fact that it is adopted, that it has become a part of our daily lives, and works so smoothly that we are scarcely aware of its existence. For example, the value of pipe thread standards is not represented by the tap and dies in the hands of pipe makers and fitters, but by the fact that because the threads are standardised, pipe fittings can be made by the million at trifling cost. The cost of changing our pipe thread standard is not represented by the cost of new taps and dies, but by the confusion involved in getting from one standard to another, a confusion which will last until all

of choice, and compelled by law to take the medicine that these doctors think will be good for them. This illustrates a radical absurdity of the metric system, applying one universal method to everything.

"Confining our attention now to measurement, with which mechanical engineers are chiefly concerned, I note, thirdly, that the metric system is absurd in ordaining a single unit of measurement for everything, from the least to the greatest, when all other systems employ a number of units, each one especially adapted to a larger or a smaller field. This absurdity stands confessed. The metricians found themselves after all compelled to employ three units, the additional ones being the kilometre for land measures, and the millimetre for mechanical measures, thus making necessary the use of three decimal points.

"Fourthly, the metric system is absurd in forbidding the use of division by continual bisection, the natural method which first occurs to everybody, and which possesses important advantages, as mentioned in the report of the Committee; thus interfering with individual freedom of choice, which is a natural right, and ordaining for universal use the decimal system of division only, the proper field of which is in the expression of very small or fractional quantities, and which is wholly unsuited to express large dimensions.

"This absurdity is realised in its utmost aggravated form in mechanical measurements, in which every dimension, however large, it was found necessary in the metric system to express in millimetres, the smallest unit, ·03937079 inch. Thus, 38 feet are 11,558 mm., and these five figures and two letters must be written. Nice to remember! We might just as well be compelled to express all divisions of the circle or of time in seconds.

"But, say the metricians, we want uniformity. Well, in the English system of linear measurement we have uniformity. It presents the very ideal of uniformity. Throughout the United States and the British Empire, all English-speaking people on the globe, in their great variety of occupations, every man who measures any thing for any purpose, all employ the same identical system of measurement. Its great practical excellence has compelled its universal adoption by men free to use the metric or any other system if they want to, and with the same freedom of choice this excellence will make its use universal.

"The proposed law excepts land measurement. The same reason would cause all measurement to be excepted from it. Yea, they are tenfold stronger in the case of mechanical measurement. It would produce quite as great confusion or chaos in mechanical as in land measurements—indeed far greater. Its disastrous effects in cutting us off from our mechanical past, and in annihilating our standards and our literature, would be inconceivable, and all for what? Echo answers, What?

"A judicious law, giving to this nation the same uniformity of weights that we now enjoy of measures of length, would doubtless be hailed as a benefit. Adherence to the proposed law, applying the metric system, which confounds measures and weights, and applies one arbitrary system to both, will bring our legislators, sooner or later, to realise that our system of linear measurement is interwoven with the life of this people; that they realise its inestimable value, and that they are fully able to maintain it.

"(Signed) CHAS. T. PORTER.

"Montclair, N.J. *December* 16, 1902."

Colonel Crompton.

existing steam, water, and gas pipes have disappeared, and it will not be lessened by putting off the change until it is brought about at the suggestion and convenience of manufacturers. It is because of our standards and our standardised methods that American mechanical industries are great. It is in this that we lead and by this sign we conquer. It is this that distinguishes us from the remainder of the world, and having the lead which such things give us, we are asked to abandon it and line up in the race afresh, and this in the name of progress."

He further went on to say that no mechanical engineering society had said a word in favour of the metric system.

If this is the state of things in America, and I believe that it is so, we in this room must see the enormous importance and immense sum of money involved in a compulsory change of linear measure when applied to the two great mechanical nations of the world.

For the reasons above given, the possibility of simplifying money, weights, and measures of capacity by decimalising them is of quite a different order of possibility to that of changing linear standards. Sellars point out that the capital expended in measuring plant, which is not likely to be scrapped or made obsolete in any way except by this change is, in the English-speaking and inch-using countries, America, England and her Colonies, many times greater than the capital already expended in the countries using the metric system. Of course this applies equally to Professor Stoney's proposal to alter the inch. If any change is possible in the future, it will be that of altering the millimetre to become the exact 25th of the inch. The tail cannot wag the dog, and in this particular instance the tail is the metric system and the dog is the inch.

Another point where the inch divided on the binary scale is superior to any system based wholly on decimal division is that of screw threads. It is found in practice awkward and inconvenient to use decimally divided leading screws for lathes, so that even in countries using metric systems most of the screws used have threads of Whitworth pitches based on the binary scale, and whenever metric leading screws are used these also are to some extent on the binary scale, that is to say they use 4-millimetre, 6-millimetre, and 8-millimetre pitch and so on; but even then they are more inconvenient than Whitworth leading screws based on the inch divided on the binary scale. Of course this defect has nothing to do with the metric system, but shows the inferiority for this purpose of the decimal to the duodecimal system of division. The result of this is that in countries using the metre we find two sets of measurements on one drawing, the metric for most of the details, but Whitworth pitches and dimensions specified for the screws. The Whitworth scale of pitches at so many threads to the inch is simple and easily remembered, but on the metric system, in order to avoid confusion and mistakes, the names of the pitches must be given in tenths of millimetres, so that we find the change wheel tables for their lathes naming the pitches in tenths of millimetres such as $\frac{77}{10}$ths and so on.

Speakers who have dwelt so much on the increased number of

Colonel Crompton.

figures and waste of time involved by the calculations when using our present system of weights and measures quite forget that since the use of the slide rule became so universal the time taken in converting from one system to the other is trifling. No electrical or mechanical engineers concern themselves with the obsolete measures concerning which so much valuable time has been wasted by some of the speakers. Practically we only have to deal with the inch divided on the binary and decimal scales, the foot, the yard, the pound, the ton, the gallon, the cubic foot and cubic yard. There is no difficulty in making calculations or estimates in these measures, and whenever it is required in converting them into metric measures we can do so by a single operation of the slide rule or calculator. The time taken in doing this is inappreciable, in fact less than the usual time taken in considering the position of the decimal point, and in practice I do not think that English and American electrical engineers users of slide rules do find any appreciable waste of time in bringing together electrical calculations worked out on the metric system with the mechanical details of their machinery based on the inch.

Maj.-Gen. Webber.

Major-General C. E. Webber: There is one point which Sir Andrew Noble mentioned that, I think, cannot be passed over, namely, that the real question underlying and behind this one as regards the brains of the nation, and as regards the education of the rising generation, is whether we are going to teach them to think in tenths or twelfths; that means, are we going to divide the pound sterling into thousandths? I remember sitting next to Mr. Gladstone many years ago, and asking him how he would agree to 10d. to the shilling. His answer was, "What would become of the apple-woman's penny?" What Sir Frederick Bramwell said at the last meeting reminded me that in the present generation the question of tenths and twelfths is largely sentimental.

I should like to remark that there is a great body of professional men in this country, numbering upwards of 33,000—I mean those connected with the building trades, architects, surveyors, and members of building firms—who are using inches, feet, and yards every day of their lives, who have to be consulted in this matter quite as much as the engineering world, which contains not half the number of professional men who use those measurements to the same extent. The only thing for which I am sorry this evening is that we have no representative of the building trades here who has worked both in France and England as I have. I should like to hear from the side of the man who has never worked with decimally divided measurements and money (as one does in France) whether he really appreciates the number of figures that are entailed by calculations in the ordinary working out of quantities and costs by the two systems. If any one will take the trouble to write down for themselves a few simple problems of cubic contents in earth-work, in brick-work, in wood-work at varying prices, and calculate them out in money, he will find that the number of figures in our duodecimal, as compared with the decimal system, is 61 to 23; that is, the actual number of figures he would have to put down on paper are nearly three times as many in the former as in the latter,

and when you come to remember the enormous number of calculations that have to be made, you will realise the convenience and saving of labour in connection with quantities and prices in building construction carried out by professional men in France as compared with this country. Maj.-Gen. Webber.

Mr. A. E. LEVIN: It is sometimes said that the comparison is between a duodecimal and a decimal system. Surely to call our English weights and measures a duodecimal system is gross flattery. We have twelve inches in a foot, it is true, but in the Avoirdupois weight there is not a single multiple of three, so that if we wish to divide a ton into three equal parts we must go to the fraction of a grain. If any division by three is necessary, which brings us below an inch, our binary subdivision of the inch becomes absurdly inconvenient. Even to one-sixty-fourth, no exact third of an inch can be expressed. Another objection which is sometimes made to the metric system is that the multiples and sub-multiples are expressed by Greek and Latin words. I have never yet heard that the Greek and Latin origins for their names have spoiled the popularity, say of the telegraph or the omnibus. Colonel Crompton has spoken of the enormous cost of the standards, the templates and gauges represented by our inches and feet in mechanical workshops. But surely the capitalised value of the mental labour which is spent and wasted in calculations in feet and inches, in acres, in miles, in chains, in the five and a half yards which go to make a rod, is enormously greater than that capital which is locked up in the foot and the inch. Mr. Levin.

Prof. R. H. SMITH (*communicated*): I can testify to the fact that errors in reading from drawings such dimensions as 12½″ instead of 1′ 2½″ are more frequent than those arising from misplacing the decimal point. This latter is an error of no great practical importance because it is one of such gigantic amount, that it cannot be carried on into practical operation. The error of reading 12½″ in place of 1′ 2½″ is entirely due to our division of the foot not corresponding with our system of numeration. If this were duodecimal, or if the base for division and multiplication of unit measures were the same as that for numeration, whatever that base might be, such mistakes could not occur. Prof. Smith.

British measures are not duodecimal. They are divided up by 2, 3, 5 and 7 with extreme irregularity. The want of system appears not only as between measures of one kind and those of other kinds: it is equally extravagant in each set of one kind. The mile is divided by 8, then by 10, then by 2×11, then by 3, then by $2 \times 2 \times 3$, then by $2 \times 2 \times 2 \times 2$. The ton is divided by 2, then by 10, then by 4×4, then by 7.

If we had a real SYSTEM of measures whose base was $12 = 2 \times 2 \times 3$, and if our numeration were also founded on this base, this would be, no doubt, better than a decimal system: but one whose base was $2 \times 3 \times 5 = 30$ would be still better, and with very little practice all educated persons could easily work their arithmetic by powers of 30. In the base 12 there is no essential advantage gained by the repetition of the factor 2. There is no ground reason for halting between the

Prof. Smith. bases $2 \times 3 = 6$ and $6 \times 5 = 30$. If 30 be really too big for our average arithmetic intellect, and 6 be too small to utilise it fully, we have to choose between $2 \times 2 \times 3 = 12$ and $2 \times 5 = 10$; that is, to choose between omitting the factor 3 or 5.

Exactitude, as distinguished from accuracy in the sense of freedom from mistake, is of no real value in any kind of practical work. The data for calculation are never known with exactitude, and a greater degree of minute exactitude in calculation than exists in the data is worse than delusive, it is often materially injurious. For this reason the selection of a base because of its richness in exact fractions of simple form is, in my opinion, of no real practical importance. The division of the circle in 12 and 24 parts is natural and easy; but this seems the only good ground for regarding 12 as a superior base. But all practical calculators know that measurement of angles by 360° to the circle is an unmitigated nuisance. One set of calculations demands the "circular" or π measurement; while in another the direct measurement of angles by their tangents or sines is infinitely more convenient. Measurement by 360° is NEVER useful: it ALWAYS involves labour lost.

What is of absolutely essential practical importance is that the base of written numeration should be the same as that on which measures of all kinds are systematised. For written numeration all nations throughout the world have adopted the base 10, and, for better or worse, are certain to adhere to it immovably. As this cannot be changed, the unavoidable conclusion is that measures should be decimalised.

It seems quite irrelevant to discuss whether the yard, metre, foot, inch or millimetre is the better standard unit. For the manifold purposes of industry it is absolutely essential to use various sizes of units of each kind. The output of a mine cannot be measured in lbs., nor bread be sold retail by the ton. For wire drawing and gauge fitting the inch unit is at least a thousand times too big, while for land surveying it is at least a thousand times too small. Thus no one unit of each kind can be said to be even approximately the best, or, indeed, to have intrinsically any advantage over another. What practical working convenience urgently demands is that all the various sizes of units found convenient in practice for each kind of thing should be interrelated by similar numerical ratios as are adopted for those of other kinds of things, and for convenience in decimal calculation all these ratios should be decimal.

The units of the metric system have no intrinsic superiority over others. The intrinsic superiority of this system lies in (1) that it is strictly systematised on one base ratio throughout, and (2) that this base ratio is 10. No other system exists which has either of these two advantages, and these two are all that are wanted or can be rationally conceived of. Any number of systems fulfilling these two essentials with other units may be devised; and, if universally adopted, any such system would be equally useful and convenient. But the metric system is already used by a large proportion of the industrial and scientific parts of the human race, and no possible advantage can accrue from its wanton destruction. For no other can possibly be better in practical essentials except in substituting for 10 the base 12

or 30 for measures and written numeration alike, and this latter is humanly impossible. Prof. Smith.

Lieut.-Col. Crompton's argument that the existing capitalised interest embodied in inch plant is greater than that in metric plant is the only strong argument against the universal adoption of metric measures. The following considerations, however, tell against it. A very large amount of mental and other labour has been embodied in the calculation and printing of logarithmic and other decimal tables, and if the necessity for the same base in numeration and in measures be recognised, and if 10 be abandoned, all this labour would be thrown away. Again there is a much larger proportion of the metric than of the inch plant that is wholly modern, and up to modern requirements of efficiency. A much larger proportion of the inch plant is near the end of its life, partly because of being worn out, and partly because of antiquation of pattern. Plant of all kinds, and especially that of antiquated type, is being scrapped rapidly, while the question of changing over to metric measures is one essentially for the future. It cannot be judged fairly, simply in view of the inconveniences and losses to be borne in consequence of it during a period of 5 or 10 or 20 years. It is a change the advantages of which will operate throughout centuries; it is quite improbable that any new alteration would be demanded for 1,000 years. Besides a comparison between the two parts into which existing plant may be divided, that whose life is already well spent and that whose life is just beginning, there is also to be considered the new plant, not superseding old scrapped plant, that will be laid down during the next 100 years, not only in Europe and North America, but also in China, Japan, Siberia, India, Australia, South Africa, and South America. The advantages to be gained accrue in respect of all this new plant recently laid down and to be created during the next few centuries, while the losses incurred by the change affect only the plant, much of which is almost dead already, and of which not a single ton will be in existence 20 or 30 years hence, except stored in the corners of historical museums.

Mr. Campbell.

Mr. ALBERT CAMPBELL (*communicated*): Although I would advocate in the strongest possible manner the immediate adoption of the metric system, I think there is one defect in it which should be remedied before the British public is asked to accept the system. I allude to the cumbrous naming of most of the metric weights and measures. If we are to throw away handy words like *inch*, *pound*, *ounce*, and *mile*, we must replace them by something shorter, clearer, and better than the French centimetre, kilogramme, decigramme, and kilometre (or Anglicised centimeter, kilogram, etc.). An inventor with linguistic imagination is wanted here.

It is to be hoped that when the metric system comes in, the *coinage* will also be made decimal. This would be a much easier matter than most people imagine, for it would be only necessary to make the *half-sovereign* the unit, and alter the copper coinage to make 10 new pennies in a shilling. The silver and gold coins would then only want renaming, and prices of 1d. a yard, or 1d. a pound would be very nearly equivalent to a new penny for a metre or a half kilogramme.

Mr. Campbell. This would be a distinct convenience to the less intelligent buyers, whilst to keep £1 sterling as unit would involve a much more difficult change.

Mr. Siemens. Mr. ALEXANDER SIEMENS, in reply, said: Gentlemen, I will begin by referring to Colonel Crompton's remarks. I was prepared to hear him say something about screws, so I had some screws made for his special delectation, and while I am replying to the other speakers I hope Colonel Crompton will look at them. There are four screws. Two are made on a lathe with a metrical lead, a 4 mm. leading screw, and two are made on a bench with eighth of an inch leading screw. Two of the screws are of $\frac{1}{8}$ in. pitch, and two of the screws are of 4 mm. pitch. Then two nuts have been made. The nut for the 4 mm. pitch is made with a French tap, and the nut for the two screws of $\frac{1}{8}$ in. pitch is made with an English tap. I should like Colonel Crompton to tell me which of the two screws are made on the mm. screw and which on the other. The screws are numbered, and I have a paper here on which it is stated where the various screws were made. This is a practical answer to the objection that English cut lead screws have to be scrapped, if metrical measures are introduced.

Colonel Crompton has stated that much extraneous matter has been brought into the discussion, and I fully agree with him. The title of the paper was, "Discussion on the Metrical System," but Sir Frederick Bramwell began by bringing "compulsion" in, a subject about which I expressed no opinion. I did not want to make any comparisons; I simply wanted to discuss what could be said for the metrical system, and what could be said against it. The question of compulsion was brought in, because I quoted what a Select Committee of the House of Commons had said. It was not my idea: it has not been the idea of the advocates of the metrical system, but it was the deliberate opinion of the Select Committee of the House of Commons—or rather two of them—that it would be to the advantage of this country to introduce the metrical system.

The reasons why the metrical system is advocated, if you omit all those external things, are based on its convenience for international trade, and for everyday use in calculation. International trade I mentioned in my remarks, although Sir Frederick Bramwell thought I did not. I said that intercommunication between countries has so very much increased during the last century, and especially during the last part of the century, that it is very desirable that a general international system of weights and measures should be adopted. That is an opinion which has been come to by other people also, notably by the Select Committee of the House of Commons in 1862. They said that it would not be desirable to create a national system, as, sooner or later, Great Britain would have to join an international system. The same conclusion was arrived at by the German Committee which was appointed about the same time. It was an instruction to this German Committee that they should find a national system, not an international one: but after they had investigated the subject a short time they came to the conclusion that it was absolutely necessary, if any change was to be made, that it should be for an international system, and that there were only two such systems

Mr. Siemens.

from which to choose, the English or the French metric system. They went into the subject very thoroughly, and the result of their deliberations was that they adopted the metric system. If this Commission had any predilection for either system, it was in favour of the English, because you must recollect that in 1862, forty years ago, everything English was considered in Germany as something extraordinarily good, and you could not give a greater recommendation than that the article was English, so that the prejudice was all in favour of England and against France. But this Commission appointed from all parts of Germany—it was not united at that time—agreed that it would be better to adopt the metrical system. After all there is some weight in that.

Not only Sir Frederick Bramwell, but other speakers have mentioned the Greek and Latin names. Mr. Levin really answered that question. The fact of the matter is that you do not use so many names. In length you use the kilometer, metre, and millimetre, and sometimes the centimetre. You use the kilogramme and gramme, and you use the litre, and for everything else you use multiples or squares and cubes of these units. We should look at the experience of other countries who have introduced the metric system—for instance, Sweden, Holland, and Germany—and have tried to invent special names in order to avoid these Greek and Latin names. In Germany they made an additional alteration. They did not adopt the kilogramme as a standard, but the pound: that was because the pound, the metrical pound, the 500 grammes pound, had been introduced long before. In 1840 it was adopted for the Customs Union, and in 1860 it was made compulsory, so they kept it in 1870 as the unit of weight instead of the kilogramme. Connected with the introduction of the pound there is a very interesting point. Some of these little German countries thought they would improve on the French system: therefore they did not divide the pound into 500 grammes, but into 30 ozs., some into 32 ozs., and others into 10 ozs. They thought by that means they would introduce a great improvement. But the general experience showed that it was much better to adhere to the pure decimal system. In Germany the metrical system of weights and measures was made compulsory in 1872, but already in 1877 the pound was given up as the unit of weight and the special names were dropped. In Holland and Sweden likewise the special names have been given up, and the pure metrical system is in use in all these countries.

I am afraid I cannot answer all the various speakers in detail, but the great point which has been brought forward against the metrical system is the decimal division. I think in this respect the objectors have put the cart before the horse, because the people who devised the metrical system did not force on an unwilling world the decimal arithmetic; but they divided the metre into decimal parts, and connected the various units on a decimal basis, because decimal arithmetic has been in use and will remain in use. I should like to ask Sir John Wolfe Barry, who is such an expert in the English and so-called duodecimal system, whether he has ever had any serious practice in the metrical system, because he will find that the moment you begin to really work in that system you will find as many short cuts in the

Mr. Siemens.

metrical system as there are in the English. It depends entirely upon what you are used to. Personally I have been entirely educated in feet and inches. I left Germany before the metrical system became compulsory, so that I must not be held up as a bad example on the other side: but in my opinion it is certainly more convenient when you have everything connected decimally the same as in ordinary arithmetic. Sir Frederick Bramwell on the last occasion was quite wedded to compulsion. He said the metrical system compelled you to use decimal fractions. The metrical people, if they can avoid it, never use a fraction at all, and that is just one of the advantages of the system. If you have to do with big weights you talk about tons or kilogrammes: if you have to do with small weights you use grammes: and if you have to use chemical weights you use milligrammes; but you never use fractions at all if you can avoid them: that is one of the advantages. On the other hand, why should you not use vulgar fractions? Sir Frederick Bramwell really gave himself away; he said, "I am not against decimals at all: I use decimal fractions wherever they come in handy." That is the answer. If decimal fractions are convenient, I use them; if vulgar fractions are convenient, I use vulgar fractions; there is nothing in the metrical system against the vulgar fraction. Why should not you talk about half a kilogramme? Reverting again to Colonel Crompton's speech, he ridiculed the German screw gauge which had $\frac{77}{100}$ths of a millimetre. I am sorry I have not the British Association screw threads here which Colonel Crompton recommended. There every one of the sizes has two decimals of a millimetre.

Colonel Crompton.

COLONEL CROMPTON: That is why I am condemning the millimetre.

Mr. Siemens.

MR. ALEXANDER SIEMENS: But in the inch scale you have given four decimals. I certainly do not believe that the period of transition would be so difficult or cause so much commotion as some people think. But one of the difficult points, no doubt, is the screw thread. All this talk with regard to Germany and other metrical countries using the Whitworth thread sounds convincing, but as a matter of fact there are no end of threads in Germany, and there are no end of threads here in this country. What has been the conclusion arrived at by the several Committees on screws, not only the Committee of which Sir Frederick Bramwell and Mr. Crompton were members, the British Association Committee, but the War Office Committee, the International Committee, the German Engineers Committee, and other committees in various parts of the world: what has been the result of their deliberations? The result of their deliberations was, that it was practically impossible to make screws fit which had been manufactured by two different manufacturers unless standard screws and standard cutters were deposited in some place where everybody could go and compare his screws with them. At the present time the War Office is putting up a standard screw machine at Bushy Park in the National Physical Laboratory, where all screws which are to be eventually supplied to the War Office are to be standardised, where people can obtain leading screws so that they can make War Office screws. Therefore the exact size of the pitch of the thread, whether in metrical measure or not, does

not matter, because eventually it comes back to the gauges and templates and standard taps. The screw difficulty, although it looks very formidable, is therefore really nothing much. Mr. Siemens.

I have one more thing to say about the subdivisions. It is always best to try and ascertain the opinion of outside people. You will find that the Commissioners for the standards of weight and measure appointed in 1841 strongly recommend the decimal division of the pound. I will read you a letter presently which has reference to that. Then there is an Institution called the Liverpool Cotton Association. They have been selling cotton, I suppose, ever since it was imported, and used, by the point. A point used to be $\frac{1}{64}$ of a 1d. Every now and then they quoted even by half a point, but after using this binary subdivision for all these years they have come to the conclusion that this binary subdivision, which has been praised so much, is not sufficiently convenient, and from the 1st of October, 1902, they have begun to make their quotations in $\frac{1}{100}$ of a 1d. They have gone over to the decimal from the binary, because they did not find it convenient.

In conclusion I will read you a letter which I received about weights and measures in a little village in Cumberland :—

"CUMBERLAND, *January 20th*, 1903.

"NOTES ON METRIC SYSTEM.

"(1) We are told that for years after the adoption of the metric system everybody would be continually doing mental conversions. But they are continually doing them *now*. Lately I told a man the depth of a shaft in feet, and he had to turn it laboriously into fathoms before he could understand it.

"(2) Another man put a cistern in his upper storey, and, wanting to know if his beams would bear the weight, asked me the weight of a cubic inch of water. He expected an hour's calculation, but by turning his inch measurements roughly into metres, or rather decimetres, I solved it in twenty seconds in my head.

"(3) I believe Sir F. Bramwell maintains that columns of tons, cwts., qrs., and lbs. are easier to add up than tonnes and kilograms. I am clerk to a mining company whose head office is in Liege, and have abundant experience of both kinds of sum. I think one page of cwt., qrs., lbs., about equivalent to three of kilos. When it comes to calculating the amount of zinc in them from a given percentage, the British system becomes practically impossible.

"(4) We are told that the pound avoirdupois is essential to British comfort. Here in the highest village in England the pound is little used. Apples and many other things are priced at (for example) '8d. a quarter,' meaning quarter-stone. The stone here was 16 pounds a century ago, now it is 14; but I have often seen small shopkeepers use a four-pound weight for a 'quarter-stone.' Evidently people who will sell you four pounds for a quarter the price of fourteen are not likely to be much troubled by the difference between two pounds and a kilogram. Evidently also they find it convenient to use a larger unit than a pound, and would therefore probably like the kilogram.

"(5) Tea, coffee, etc., are priced by the pound, but are always put up in quarter-pound packets. This shows that the hectogram would be a convenient unit.

"(6) In our laboratory is a set of weights marked in 'septems.'

Mr. Siemens.

When I came here no one knew what they were, but I found a 'septem' was 7 grains, $\frac{1}{1000}$ of an avoirdupois pound. This shows that attempts to decimalise the British measures fail.

"(7) Lead ore here is measured by the 'bing' of 8 cwt. Zinc blende, obtained at the same time from the same mines, is weighed in tons. The rough 'bouse' from which both are extracted is measured in 'shifts'; a shift is supposed to be 4 tons. Miners are paid by the 'cubic fathom' of $6 \times 6 \times 4$ feet. The present mining company, despairing of ever putting this chaos straight, is gradually replacing all these measures by kilograms and cubic metres.

"(8) A gill in the schoolbooks is ¼ pint; in trade here it is ½ pint.

"(9) When we buy timber it is invoiced thus: '1 st. 1 qr. 16 deals 4/6 at £16 a standard.' A 'standard' is 120 'standard deals,' each of which is $72 \times 11 \times 3$ inches in England and $144 \times 9 \times 3$ in Ireland. The 'standard' is divided into 4 quarters, each of 30 'standard deals.' This bewildering system (which is not to be found in *Whitaker's Almanack* nor any other book of reference within my reach) is confined to the wholesale trade; smaller dealers sell by comparatively intelligible units of 100 square feet.

"(10) The mugs distributed to the children at the Coronation were just ¼ litre.

"(11) A Swedish lady here ordered a dress from the village dressmaker and gave the measurements in centimetres. The dressmaker begged a metre-tape from me and made the dress without the least difficulty."

I think that shows how difficult it is to learn the metrical system.

The President.

The PRESIDENT: I will now ask the meeting to pass a cordial vote of thanks to Mr. Siemens and Sir F. Bramwell for their contribution to the discussion.

The PRESIDENT announced that the scrutineers reported the following candidates to have been duly elected, viz.:—

Members.

Clement Johnson Barley. | Prof. W. C. Unwin, F.R.S.

Associate Members.

Robert Alexander Raveau Bolton.
Claude Greener Cadman.
Geo. Henry Clapham.
Alfred Lawrence Eugene Drummond.
Frank Edmondson.
Geo. Emerton Higginbotham.
Charles James Jewell.
Reginald Keble Morcom.
Ernest Probert.
Charles Edward Squire.
Walter Noble Twelvetrees.

Associates.

George Edward Anness.
Alfred Anthony Blythen.
James C. Cunningham.
Lewis William Dixon.
Samuel Slack Foster.
John Godfrey Y. D. Morgan.
Edward Phillips.
James Arthur Sykes.
Robert Alexander Ure.
Maximilian J. L. Weston.

Students.

Frederick Creedy.
Erich Egon Edmund Dormann.
Frank Donald Howard.
Harold Carnegie Jenkins.
Arthur Henry Knight.
Archibald Charles Lock.
Herbert Richard Marr.
Douglas William Munton.
Chas. Wm. George Nelson.
John A. G. Ogilvie.
Frederick Handley Page.
Enrico Arthur Pinto.
Frank Bennett Preston.
Carl Hubert Sanders.
John Henry Charles Searle.
Claude Theodore Sielis.
Frederick Swarbrick.
Richard Henry Turrall.
Leslie Wainwright.
Herbert Wilson.
Wm. Francis Wolfe.
Ernest Benjamin Woollan.

The Three Hundred and Eighty-fifth Ordinary General Meeting of the Institution was held at the Institution of Civil Engineers, Great George Street, Westminster, on Thursday evening, January 8th, 1903—Mr. JAMES SWINBURNE, President, in the Chair.

The minutes of the Ordinary General Meeting held on December 18th, 1902, were read and confirmed.

The names of new candidates for election into the Institution were announced, and it was ordered that these names should be suspended in the Library.

The following transfers were announced as having been approved by the Council —

From the class of Associate Members to that of Members—

Arthur Thomas Cooper.
Forrester Ferguson Ferguson.
Joseph Robert Woodruffe Gardam.
Norman Rheam.
Walter Adolph Vignoles.

From the class of Associates to that of Members—

Major Walter Arthur John O'Meara, R.E.
Lionel Hugh Kenmure Stotherd.

From the class of Associates to that of Associate Members—

E. E. Benham.
Jas. Brown.
John Brown.
Thos. Carter.
Alfred Charles Cossor.
Arthur W. Cox.
Ernest Holmes Llewelyn Dickson.
Fourd Ely.
Cecil Chas. Fowler.
Reginald Wilson Gauntlett.
John Owen Girdlestone.
Edmund Goolding.
John Gray
Henry Human
Edward Henry Johnson.
Chas. Keeble.
T. Kerr-Jones.
Lionel Jas. Langridge.
Robert Andrew Miles.
Edwin Morgan.
Hugh Bernard Player.
Oliver Archer Richardson.
C. W. Schaefer.
Francis Sydney Shaw.
Eustace Graham Sheppard.
Sidney Arthur Simon.
Chas. Wm. Spiers.
Leonard Geo. Tate.
Wm. John Thorrowgood.
Max. Jas. Eccles Tilney.
John Frederick Wakelin.

From the class of Students to that of Associates—

Arthur Buckney.
Jas. John Chapman.
Harold Frodsham.
Geo. Hicks.
Henry F. Jay.
Frank Clement Knowles.
Edmund Lewis Robinson.
R. E. S. Turnbull.

Messrs. F. C. Hounsfield and L. L. Robinson were appointed scrutineers of the ballot for the election of new members.

Donations to the *Library* were announced as having been received since the last meeting from Messrs. Macmillan & Co. and Prof. S. P. Thompson; to the *Building Fund* from Messrs. E. Coates, P. F. Crinks, H. W. W. Dix, W. Duddell, J. H. Edwards, W. Golledge, T. F. Griggs, C. W. Hacking, R. Hammond, Prof. A. Hay, A. P. Hutchinson, Captain Jackson, H. W. Miller, H. B. Mitchell, G. Offor, A. P. Patey, W. M. Rolph, J. H. Rosenthal, A. Rutherford, W. H. Shephard, J. M. Smyth, M. Solomon, A. Stroh, A. A. C. Swinton, L. C. B. Trimnell, A. S. Wilson, H. W. Young; and to the *Benevolent Fund* from Mrs. Ayrton, Messrs. C. P. Cobb, G. J. Gibbs, T. F. Griggs, S. H. Holden, Sir David Salomons, W. C. Smith, A. Stroh, W. C. P. Tapper, J. Woodside, and the Incorporated Municipal Electrical Association, to whom the thanks of the meeting were duly accorded.

NOTES OF RECENT ELECTRICAL DESIGN.

By W. B. Esson, M.Inst.C.E., Member.

In the course of their visits to the Continent, members of the Institution had ample opportunity of studying the construction of electrical machinery as illustrated by the practice of Europe and America. Work representative of the best that has been done was everywhere open to the inspection of the tourists, and every facility was placed at their disposal for comparison of different designs.

In the course of this paper I shall have occasion to refer frequently to what was seen, and in this respect the Notes may to some extent supplement the excellent reports already furnished to the Council by the various German Visit Committees.

Introduction and Review.

By way of introduction I must take you back to the Electrical Exhibition held in Frankfort eleven years ago. At that superb show, in 1891, was to be seen the best that the Continent had done in construction up to that date, and it will be recollected that there was manifested considerable diversity in the type and form of machines.

Beginning with continuous current, there were in addition to the multipolar dynamos with slotted drums, the wheel-armature machines of Fritsche, the flat-ring machines of Schuckert, and several interior pole ring-wound machines by different makers, of which the largest and most notable was the one shown by Messrs. Siemens & Halske, running

at 80 revolutions per minute, to give 300 kilowatts. Of these, all have disappeared with the exception of the multipolar machines with radial magnets and slotted drum armatures. This is the only surviving type on the Continent, and it is now the prevailing type with us.

Ten years ago it looked as if in Germany the interior pole machine was to become a permanent type, since several manufacturers had taken it up, but it has gone with the others referred to. Though such machines have done and are doing their work in a very satisfactory manner, the design has faults both electrical and mechanical which are absent from the design which has replaced it. Accordingly, as a standard type, it has ceased to exist, and there are now made, only the occasional machines asked for by customers who wish their new plant to be uniform with what had been previously supplied.

In this country at the date of the Frankfort Exhibition the drum armature was rapidly supplanting the ring armature for all sizes of machines. The single magnet type of field was in general use by all makers, though some of the more important firms had been coquetting with multipolar designs. A paper of mine read before this Institution in 1890 calling attention to the advantages to be derived from multipolar fields elicited from some quarters a vigorous defence of the 2-pole. Slotted armatures had not come in, or, rather, they had come in and gone out again, because too costly at that date with hand coiling for bipolar fields. With the advent of multipolar machines came former wound coils and shaped bars, and the slotted armature once more made its appearance, this time to stay.

What has happened during the past ten years, then, as regards continuous-current generators is this: all lines of design on the Continent, in America, and in Britain have converged towards one form, which is likely to be permanent. There is practically but one type and one form of that type, differing merely in its proportions and constructional details; this form is to be seen in every new generating station—a multipolar machine with its magnets disposed radially and provided with a drum armature slotted on its exterior for the conductors.

Of alternators there were but few at Frankfort, the most worthy of note being the two machines exhibited by the

Helios Company and Messrs. Siemens & Halske respectively. The former gave 400 kilowatts at 125 revolutions per minute, and the latter 330 kilowatts at 100 revolutions, both machines being therefore of about the same size. Each had a stationary armature and a rotating field of radial magnets mounted on the engine fly-wheel. The armatures of both were of the pole type—that is to say, their iron cores had distinct interior projections corresponding to the number of the field-poles. The Helios machine was a modification of the well-known Ganz alternator described here by Professor Forbes in 1889. The Siemens & Halske armature was practically a large-sized Gramme ring with projections between the coils. Taken as a whole, the Exhibition was rather poor in alternators. There were few polyphase machines, while in the Paris Exhibition of 1900 there was little else.

At the same date there was over here considerable variety in alternators. There were the machines which had copper tape armatures without iron, some of these having stationary and some rotating fields. Then there were machines having flat coils laid on the surface of the armature core, these, again, being divided into those with fixed and those with moving fields. There were iron-cored armatures with polar projections and without, also armatures wound like Gramme rings. In some machines the fields were excited by a single coil, and in others by multiple coils, while last of all we had the inductor alternator of the late Mr. Kingdon, where the field and armature systems were fixed and the path of the magnetic induction was determined solely by the movement of blocks of laminated iron attached to a rotating central wheel.

The alternators on the Continent and in England were in 1891 on their probation, so to speak, and ten years have done much towards reducing the number of types. The copper tape armature is no more, that is in the manufacturing sense. Probably a few such machines are made for the sake of uniformity in the extensions to existing stations, but no engineer would think of introducing for new works machines of the coreless type. The drift of practice has been towards making the alternator in all respects satisfactory from an engineering point of view. It must be, first and foremost, a *machine*, and a machine that will run continuously without giving trouble. There is no

doubt that iron-cored alternators can be constructed more in accordance with the principles of sound engineering than can those having armatures without iron, in which the coils, long and thin, are supported in a not very mechanical manner at one end only. Engineers have come to regard such machines as unsuitable for prolonged hard work, and especially is this the case when the armature is stationary. Under the latter condition, soundness in mechanical construction is very difficult of attainment. The fact is that the insulating materials, micanite, fibre, stabilit, ebonite, slate, etc., upon the strength of which the durability of such machines depends, are quite unfit to endure stress or to transmit power. In up-to-date alternators there is no force transmitted through the armature conductors, nor is there any mechanical stress to speak of on the insulating materials.

It used to be thought that coreless armatures had no self-induction, while cored armatures possessed this particular characteristic in great degree. The idea was based on erroneous conceptions of the magnetic circuit and armature reactions. Now we know that essentially there is no electrical difference between machines with iron cores and those without, and that with proper designing there is no difference with respect to armature reactions. But, it may be remarked, the coreless machine was wholly unfitted for polyphase work.

Of the cored class, armatures with well-defined poles, such as were used by Ganz and others, have disappeared. Perhaps no firm has done more or better work than the Buda-Pesth firm, and up to 1896 their alternators did not sensibly differ in design from the machines they installed at Rome in 1885. But at the Paris Exhibition this design was missing, and really it was not before time. In the machines referred to, the resistance of the magnetic circuits varied greatly for different positions of the magnets relatively to the armature coils. When the poles were in line with the coils the air-gap was comparatively small, and the induction path was mostly through iron. When the poles occupied a position midway between the coils, however, the magnetic resistance was comparatively high, and the inductive path was largely through air. The result was loss of power in field hysteresis and a great amount of noise, while the flux through the magnets varied

between maximum and minimum, with a frequency equal to twice that of the machine, and in the exciting circuit disturbing E.M.F.'s of the same frequency were set up, due to the flux changes. By the thorough lamination of every part of the magnets as well as of the armature it would appear, however, that this variation in the field flux did but little harm, since the alternator in its day had an efficiency probably second to none of the Continental machines.

After the Frankfort Exhibition, Herr Coerper, of the Helios Company, modified the Ganz machine by providing the radial inwardly projecting cores of the armature with extensions, thus spreading the iron out in front of the coils, so that when the sectors, of which the core was made up, were all in place the surface presented to the field magnets was interrupted only by narrow spaces. It will be seen that this was a considerable improvement on the Ganz machine in the sense that the hysteresis loss in the magnets was reduced; the exciting flux was not subject to such large variation, and the exciting current was in consequence comparatively steady.

In the beginning of 1894 Mr. Kapp patented a modification of the Coerper machine, the improvement consisting in increasing the mass of the iron in the core sectors and enlarging the area of the joints between the sectors, thus making the core less discontinuous and reducing to a minimum the spaces left in the core for the accommodation of the coils. In all these machines the number of armature sectors was equal to the number of field-poles, the armature coils enveloping the separate sectors, and in Coerper and Kapp's machines being sunk into grooves in the sides. But it will be obvious that in all, the magnetic flux varied, with the relative position of the poles, though in the last-named machine to a very much less extent than in the first. When the field-poles were opposite the armature coils, the path of the induction from pole to pole included a joint between a couple of sectors, while on the other hand when the poles were in an intermediate position no joint was included. There was, therefore, though it might be small, a distinct difference in the reluctance of the magnetic path for different positions, and the variation of the magnetic flux due to this must have set up to some extent wasteful parasitic currents in the mass of the field magnets. The author

endeavoured to get rid of the imperfection above referred to by reducing the number of sectors and armature coils to one-half the number of field-poles. In his 1895 design each coil was embedded in the centre of a sector, being wound through two holes, and no part of the coil being near the joints the core sectors could be butted together, thus securing what was practically magnetic continuity for the core. With half the number of joints, even if they were imperfect, there was little danger of their producing a variation of flux through the magnets, since, whatever the position of the poles relatively to the armature coils, there was always a clear path through jointless iron for all the lines from pole to pole. This being so, hysteresis loss was avoided and lamination of the poles throughout rendered unnecessary. Many of these machines are at work, but they are not made now. The sector form of armature is costly to construct, and it offers no advantages to speak of, while it is ill-fitted for polyphase work.

These several designs illustrate well the evolution of the alternator in recent times. At first the armature had well-defined poles, and there was great magnetic discontinuity in the built-up core. The poles were then spread out at their extremities until they presented a nearly unbroken surface to the magnets, and there was in consequence some approach to continuity. Then the armature was filled up with iron, only such space being left as was required for the conductors. Finally the sectors were reduced to half the number of poles, in order to get what was equivalent, so far as magnetic flux was concerned, to perfect continuity. From this to the modern form of machine, with its armature core built up solid and constructed of interleaved segments pierced with holes, is but one step further in the evolution.

The field magnet introduced by Mr. C. E. L. Brown, excited by a single coil, is a thing of the past, the inherent defects of this type having forced it into disuse. This design undoubtedly showed a considerable saving in the copper required for the fields, with corresponding economy in the energy required for excitement, but the disadvantageous disposition of the field-coil and excessive drop in volts from no-load to full-load, when working on a circuit even moderately inductive, rendered machines with such fields unsatisfactory, especially for transmission work.

Added to this there was, owing to the magnitude of the stray field, difficulty in predetermining the path of the useful flux with accuracy, and predictions of the output could not be made with certainity.

In another form of field excited by a single coil, the poles projecting from the central core instead of being bent over to present a series of north and south faces lying in one circle were cut off, so that they formed a crown of north poles on one side and south poles on the other, the armature core being divided into two parts to correspond. This design allows of the field-coil being stationary, and to machines so constructed was given—not with much reason sometimes—the name "inductor-alternator." This type of generator attracted considerable attention on the Continent some five or six years ago, and much was hoped from it. Herr Dolivo-Dobrowolsky, the chief engineer of the Allgemeine Company, took it up with zeal in the belief that it would come to the front and stay there; but, alas! it has gone with many others. At the Paris Exhibition there were only one or two such designs, and when the members visited Germany none were in hand. The machines which were put into use some time ago are, of course, running and doing good work, but as a standard the type has ceased to exist. The fact is that the total weight of material in these designs much exceeds the weight in those with multiple field coils, so that there is no real economy in construction. The necessarily small air-gap which had to be employed is unfavourable to the production of a purely sinuous E.M.F. curve, while they have been found unsuited for power work because of the disadvantageous position of the exciting coil, already referred to, and the induction of opposing E.M.F.'s in portions of the armature winding. The shaft and engine parts of such alternators are magnetised, which is another disadvantage, but, to crown all, the machine, so far as its field is concerned, is illustrative of the foolishness of putting all one's eggs into one basket. It is all very well for small machines, but the work involved in repairing a large alternator of this type, should a field-coil happen at any time to become *hors de combat*, can only be contemplated with positive dismay. In all designs the primary object should be to secure immunity from breakdown, but it is of scarcely less importance that should at

any time a breakdown occur the repair should be effected with the greatest facility.

It comes to this, then, as regards alternators, that taking all the divergent types which were the vogue, the lines of evolution proceeding from each as an origin have been, during the past decade, convergent towards one type. This type, which is common to America, the Continent, and this country, is a machine with rotating radial magnets energised by multiple coils, having a cored armature with a cylindrical surface presented to the fields, and the winding lying in holes or slots below, but close to, the surface of the iron. Of other types there are a few, and there will always be special designs to suit particular circumstances, but the above is the standard and, there is reason to believe, the permanent type. There are in use two forms of it, one with the armature encircling the poles, and one with the poles encircling the armature, but machines of the former class are greatly in the majority.

Conditions Affecting Design.

Though general agreement has been reached as to the type and form of generators, agreement with respect to proportions or details of construction has not yet been arrived at. This is due largely to the variety of conditions which designs have to fulfil, while every machine, of course, is stamped more or less conspicuously with the originality of the designer, representing, as it must, the results of his study and investigation. On the Continent they have gone in solid for low speeds, and there machines are invariably driven by vertical engines of the marine type or by horizontal engines, such as are made by Weyher and Richemond or Sulzer. The difference in the speed of engines of similar size made by different makers is inconsiderable, while the difference in speed between the smallest central station engine and the largest is not great. A 500 H.P. engine, for instance, will run at 120 revolutions per minute, while a 3,000 H.P. engine will run at 83 revolutions. In this country we have quite a different state of affairs, and while the high-speed engine is at present in general use, there are really all sorts running at all speeds. One never knows

here what size of generator has to be supplied for a specified output, and to the multitude and variety of engines is to be attributed, in large measure, the little progress that has been made in the standardisation of large machines. So long as we had only one high-speed engine to fit we got on very well; but now there are at least half a dozen, no two of which correspond for power, in speed. Not only so, but we have 2-crank and 3-crank engines by the same makers, the latter, seeing that each individual line of parts is much lighter, running at considerably higher speed than the former for the same power. And, as if all this were not enough, we have Mr. Mark Robinson making observations of periodic oscillation of fly-wheel systems, which cause his firm to demand that the armature body of the generator shall always form an inherent part of the engine fly-wheel, thus necessitating extra pattern making. On the Continent, so far as I can learn, the designer has none of this worry to contend with.

Owing to the general adoption of low speeds, the frequency of continuous-current machines is on the Continent lower than with us. Take, for instance, the continuous-current sets running at the Hanover Central Station, which have an output of 400 kilowatts. These machines are coupled to vertical engines running at 120 revolutions per minute, while machines of the same output would with us be coupled to high-speed engines running at 300 revolutions per minute. In the former the frequency is with 10 poles, 10; in the latter, with 6 poles, it is 15. Siemens & Halske's 1,000 k.w. machine at the Paris Exhibition running at 95 revolutions per minute had a frequency of 11; the Siemens Brothers' 1,500 k.w. machine, running at 200 revolutions, had a frequency of 26. Lahmeyer's 350 k.w. machine at the Paris Exhibition had a frequency of 9·4, while the large 1,500 H.P. machines at the Berlin Central Station run at 83 revolutions and have 16 poles, corresponding to a frequency of 11. From these figures it appears that on the Continent the usual frequency for continuous-current generators is from 9 to 11, while with us it is fully 50 per cent. higher. In passing, it is worth while noting that in machines of similar *power*, provided the core induction is the same, the hysteresis loss is practically unaffected by frequency, and the percentage of power

wasted in hysteresis is virtually settled by the induction in the iron. At first sight this appears somewhat strange, but it is capable of easy proof. After all it is only reasonable to suppose that there is some definite relation between the energy output of the machine with which the mass of iron is associated and the energy spent in the magnetic manipulation of the mass itself.

But in determining the output-coefficient of a given size of armature, the question of speed and frequency is of considerable importance. Calling D the diameter of the armature in inches, L its length in inches, and R the number of revolutions per minute, by output-coefficient is to be understood the value by which $D^2 L R$ has to be multiplied to give the output of the machine. The machines at Hanover have been referred to, and the armatures of these may be taken to illustrate my meaning. Let us imagine that we increase the speed by 50 per cent., making them run at 180 revolutions per minute instead of 120. The frequency would then conform to English practice, being 15 instead of 10. Temperature is the factor which limits the output, as the proper course is to find for any given size of armature the load which corresponds to the maximum temperature rise permissible and then to rate it at that. Well, we find that if this temperature rise is not to exceed at the higher speed the figure attained at the lower, for a 50 per cent. speed increase the output cannot be increased by more than from 25 to 35 per cent. The exact figure is a matter for experiment and depends upon the construction of the armature. Even if we increase the depth of the core under the slots by 50 per cent. and assume that the added depth is effectively on a par with the original depth, which it is not, we shall still have an output-coefficient considerably reduced on the high-speed machine. This means that the output-coefficient of an armature depends upon the speed at which it runs and explains its much higher value in some of the slow-speed Continental machines. If I might use Mr. Mavor's term, the so-called active belt becomes more active as the speed is reduced. But, unlike Mr. Mavor, I find little agreement in the output-coefficient between the machines of different makers. I have compared a very large number, but I will not trouble you with the con-

stellation representing the results, as it indicates no law. While adhering to the conditions that the frequency shall be about 10, that the temperature rise after a six hours' run at full load shall not exceed 40° centigrade and that there shall be no sparking, there is possible, of course, great variation as regards the length of air-gap, the air-gap induction, the ampere bars on the armature per pole, the number of poles, and so on, but on the whole it is easier to design a satisfactory low-speed machine than a high-speed one.

Not very long ago the late Prof. Short, in a paper read before the Manchester Section, proposed a series of machines embracing sizes from 137 to 2,000 k.w., and all consistent as regards efficiency, temperature rise and sparking, and overload limits. This result was obtained by keeping the length of armature the same throughout the whole series and varying the diameter. The number of commutator sections and conductor bars was to be proportional to the diameter, and there was the same current per conductor path for all sizes. The number of poles was proportional to the diameter, while the speed was inversely as the diameter. The proposition was simplicity itself, but our present ideas respecting engine designing prohibit us from putting it into practice. The engine speeds, for instance, do not vary inversely as the power, nor does it appear in the nature of things that they should do so, though this is a condition which Mr. Short's proposition involves. If the engine of a machine for 1,000 k.w. has a speed of 95 revolutions per minute, the engine coupled to a 2,000 k.w. machine will not run at 48, nor will that coupled to a 3,000 k.w. run at 32. The speeds of these will be about 85 and 75 revolutions respectively, and the dynamos will have to be designed to suit. As a matter of fact, the speeds given by Mr. Short are for the smaller sizes too fast and for the larger sizes too slow; and much as we should like to do so, it is impossible, having regard to economy in engine design, to arrange that all the different sizes of dynamos shall be multiples of one particular unit. The extra expenditure involved in the construction of steam sets running at such unnecessarily slow speeds for the large sizes, as Mr. Short advises—53 revolutions for a 2,000 k.w. machine—would more than counterbalance any advantage gained from carrying out in design the multiple unit idea.

In alternators the frequency is fixed, but the design is considerably modified by attachment to high, instead of low, speed engines. Taking a 3-phase alternator of 750 k.w., the field of this machine mounted on the shaft of a low-speed engine, such as is met with everywhere on the Continent, would run at close on 94 revolutions per minute, and would measure, say, 18 feet across the pole-tips. Now a machine of the same output coupled to a high-speed engine would probably run at 200 revolutions per minute, and the diameter of its field would be 10 feet. This gives a periphery speed of over 6,000 feet per minute, and though this has been exceeded, I must say I think it quite high enough. Not only are the poles now heavier, but the tangential inertia per unit of mass is greatly increased, demanding a greater proportion of the fly-wheel rim to be drilled away for the larger bolts required. Such a fly-wheel would, of course, have to be made of steel, the rim and arms being solid and the boss split triangularly and steel-hooped. To get the output, the width of the machine must be half as much again, so that if the low-speed alternator were 12 inches, the high-speed one would be 18 inches, the proportion of width to diameter being therefore altogether different in the two designs. If the core induction were in both machines the same, in each the same quantity of heat would be produced, due to hysteresis loss, the mass of soft iron to magnetise being the same; but as the radiating surface has been in the smaller machine reduced by some 20 per cent., it is obvious that if the output-coefficient is to be maintained at the same figure in the high-speed machine as in the low, more efficient means of carrying off the heat must be provided. It is necessary to bear in mind all these facts when comparing the designs seen here with those seen abroad, and it does not do to conclude that what is good proportion for one case is good for another where the conditions are quite dissimilar.

Continuous-current Machines.

Returning to continuous-current generators, there is not a great deal of difference between the practice abroad and what we are accustomed to here. The number of poles for a given diameter of armature varies in different designs, but

generally speaking there is in large machines a pair of poles for every 15 to 18 inches diameter. Rarely do we find the current to exceed 300 amperes per set of brushes, which corresponds to 150 amperes per path in a parallel wound armature. The output varies from 100 to 150 kilowatts per pair of poles.

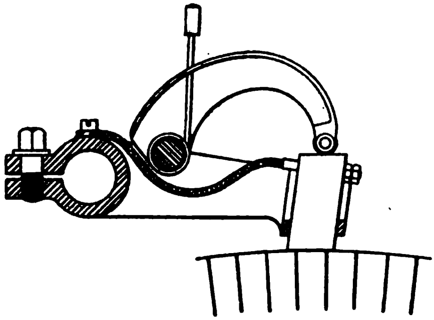


FIG. 1.

Carbon brushes are now universal, and a great deal of ingenuity has been expended on the effort to obtain a thoroughly satisfactory brush-holder. Nothing is of more importance in the design of a machine than the brush gear, and as illustrating the many different forms devised, perhaps no collection could surpass that at the recent Glasgow Exhibition, where all kinds were to be seen. Under three classes nearly all the brush-holders in use can be grouped, viz., the slider holder, the hinged holder, and the reaction holder. In the former the carbon slides in a rectangular slot, being pressed directly on the commutator by a spring, or a toe operated by the spring; in the next, a carbon is firmly secured to a hinged arm on which pressure is put by a spring; while in the last the carbon is in the form of a triangular wedge, one side of which is kept up to the commutator by the force resulting from a spring pressing on another side and the reaction of the brush-holder surface, against which rests the third side of the triangle. These different forms are represented in the sketches, and all give satisfactory results, but of the three the slider form seems

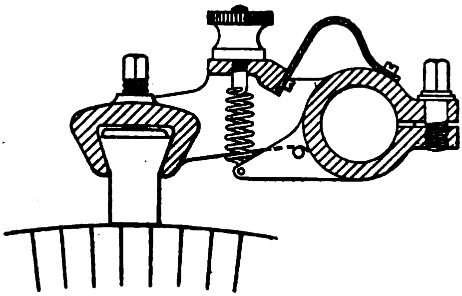


FIG. 2.

the most in favour. Whatever is used, it is necessary to have the moving parts as light as possible in order that the brush may promptly respond to infinitesimal irregularities in the commutator; some makers using the second class of brush-holder construct the hinged arm of aluminium for the sake of lightness. That the pins or brackets carrying the brush-holders must be absolutely rigid goes without saying, as well as the ring to which they are attached. The fixed ring carrying the whole of the gear may be supported either by brackets from the yokes, or may be attached to the pedestal next the commutator. One method is just as good as the other, but the former must be employed when the armature is fixed in the middle of the crank-shaft between the engine cylinders, while the other is the more suitable for machines of medium size coupled to one end of the engine shaft. The construction in the latter case is somewhat simpler than when the bracket supports from the yokes are adopted, but personally I should like to see the whole paraphernalia of adjustable ring, screw gear and hand wheel swept away, the brush-holders, after testing the machine, being fixed rigidly in one position to suit all loads.

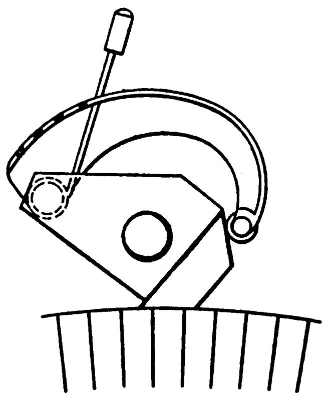


FIG. 3.

The construction of the poles and yokes in the Continental machines is much the same as with us. In the machines of the Allgemeine Company and Schuckert the magnet cores are of solid steel cast in one with the yokes. The former company fit on to each magnet a pole-shoe, which is made by cutting into segments a steel ring turned inside and out, and this shoe is fastened to the magnet by screws. The Union Company of Berlin cast the steel magnet and polar extension in one, and screw the same on to a yoke of steel or cast-iron as the case may be. The eternal question of steel deliveries is as pressing on the Continent as with us, and at the time of the Institution visit the Allgemeine Company was settling it by adopting cast-iron for their yokes instead of steel, and using laminated

blocks for their magnets. The latter were being made of thin plates riveted together and screwed on to the yokes, being drilled and tapped for the screws just as if they were solid. The plan of casting the laminated blocks into the yokes does not seem to have been adopted by any makers on the Continent. The experience of my firm is that a laminated pole offers no advantages as regards efficiency, while it has several disadvantages, not the least amongst which is the increased tendency to bucking observable with their use. There is less work in a machine having solid steel poles cast with extensions screwed on to a cast-iron or steel yoke, and the benefit derived from the adoption of the circular section in saving field copper is considerable. German steel is, I find, inferior to English steel, but it is much cheaper in proportion, the result being that even when the extra field copper is taken into account a machine made with German steel is cheaper than one made with English. On the Continent, as with us, the usual ratio of pole arc to pole pitch is ·66–·7.

The machines inspected in the Berlin station on the occasion of the Institution's visit excited universal admiration. These continuous-current sets are capable of giving each 1,500 E.H.P. at 250 to 280 volts, and are coupled one on each end of the crank-shaft of a 3,000 H.P. vertical engine running at 83 revolutions per minute. Each machine has 16 poles, and the armatures look about 12 ft. in diameter. The air-gap is about $\frac{3}{4}$ in., and the induction in the gap is 8,000 C.G.S. units per square centimetre. The plan of mounting continuous armatures directly on the crank-shaft between the engine cylinders appears to be viewed with disfavour on the Continent. Alternators there are in plenty with their rotating fields so placed, but generally speaking continuous-current machines are coupled on one or both ends of the crank-shaft. Coupling two generators to one engine permits of earthing the middle wire of the three-wire system without inconveniences due to rise of pressure on one side should the outer of the other become accidentally earthed. Lahmeyer, it will be remembered, secures similar immunity by connecting the earthed neutral wire to the middle point of the generator armature.

Visitors to the works of the A. E. G. may have observed that in the smaller machines the strips con-

necting the commutator segments with the armature windings were made of nickeline for the purpose of introducing resistances into the two short-circuited coils, a row of small holes being pierced in the strips for the double purpose of further increasing the resistance and ensuring rapid cooling. The practice of this company differs from that of other manufacturers in that the slots in the armatures of their dynamos are much smaller and the current density in the conductors correspondingly greater, reaching in some cases as much as 3,600 amperes per square inch of section. On the Continent there are no commutator end clamping rings in the larger machines, but in lieu thereof a number of clamping pieces, each secured by one or two studs, the pieces being made by cutting the ring, turned first to the proper wedge shape, into short pieces. It will be readily understood that this gives much greater facility for replacing segments than if a continuous ring were used. An interesting variation is afforded by the practice of Messrs. Brown, Boveri & Co., who make the commutator drum with a flanged end and tighten the segments by wedges placed circumferentially on the drum and pulled down radially. (See sketch.)

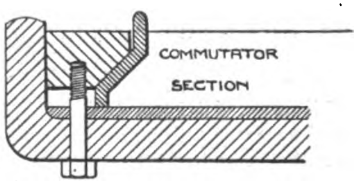


FIG. 4.

ALTERNATING-CURRENT GENERATORS.

Dealing with alternators, there was in single-phase machines nothing to speak of in Paris or Berlin, and it is unlikely that, save for extensions to existing stations, there will be further single-phase machines installed in this country. I have already referred to the design which has been universally adopted for polyphase alternators, and will now touch on some of the variations. The plates constituting the armature core are contained in a massive cast-iron circular frame, which has to be made very stiff in order to resist deformation, and several devices have been adopted with a view to getting maximum stability with minimum weight of material. Messrs. Brown, Boveri

secure to each side of a cylindrical shell a wheel-casting with arms extending to central hub or boss, this latter being bored out to fit on trunnion rings cast concentric with the bearings. This construction converts the whole armature into a wheel supported on a couple of trunnions having two sets of arms, between which the flywheel rotates inside a cage, so to speak. The construction is, of course, very rigid, besides admitting of the armature being rotated on the trunnions, and provision so made for examination of any of the coils needing attention. Messrs. Lahmeyer, of Frankfort, in building their armature frames also attach to each side of the containing shell, wheel-castings. They have arms like the Brown-Boveri construction, but these do not terminate in a boss bored out to rest on a trunnion. Generally they terminate in a ring just large enough to properly clear the shaft and brush gear. The 100 k.w. machine at the Paris Exhibition, for instance, had frames of this kind with ten arms in each casting. On occasions, however, the inner rings of these wheels are considerably larger than are just required to give clearance for the brush gear. In fact they may be half the diameter of the armature or more, in which case the castings, still consisting of concentric rings connected by radial bars, merely serve to increase the depth of the shell, and so give it additional stiffness. Messrs. Schuckert have endeavoured to stiffen the armature frame by connecting by means of radial stretcher rods the cast-iron shell at different points to a ring concentric with the shaft. It will probably be remembered that the 850 k.w. machine at the Paris Exhibition was stayed in this manner, the ring being made large enough to properly clear the brush gear for the field magnets. In this case the weight of the armature, instead of being as in the construction of Messrs. Brown, Boveri, taken by trunnions, is borne by the feet cast at opposite sides of the shell. Several designers, however, ignore these methods, and trust to the stability which can be obtained from making the section of the shell of box form or of a deep **U** shape. It is worthy of note that the largest alternators seen during the tour in Germany had no devices of the kind described. I am referring now to the machines at the Moabit station of the Berlin Electricity Works, giving 3,000 k.w. at 83 revs. per minute. These, if not the largest

generators in the world, were, up to the date of the Institution visit, the largest constructed in Europe. Matters may be so arranged that the lower half of the armature receives additional support from a pedestal placed directly underneath the shell and resting on the foundations. All the devices just mentioned are for the stiffening of a shell containing the core plates, but by far the most interesting design in armature frames was that presented by the departure made recently by the A. E. G.—the makers, by the way, of the large alternators above referred to—who proposed to do away with the cast-iron shell altogether. For this are substituted a couple of side-rings to clamp the core plates up, and from the latter radial struts project, which are connected together by tie rods, the whole forming a lightly-built framework of sufficient strength to support the armature core, and of a sufficient stability to resist deformation. A machine built on these lines, giving 1,100 k.w. at 107 revolutions per minute, was seen working on probation; others are being installed at Manchester, and, if successful, the construction will constitute a distinct advance. Mr. Dobrowolsky asserts that as compared with the usual design the saving in weight of materials required in respect of a given output will be about 20 per cent., and the saving in cost of construction about 10 per cent.

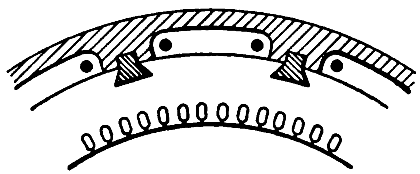


FIG. 5.

In modern alternators the segmental core plates are clamped tightly together by stiff outer rings, the tightening bolts in most cases going right through the segments and providing the means of securing these in the containing shell. When firmly clamped up the rings are secured in their place by screws passing through the shell, and it is now unusual to insulate the through bolts in armatures of this construction. The holes are punched close to the outside edge of the segment, say within one-eighth or three-sixteenths of an inch, and it appears that there is very little loss of power due to the field straying in this portion of the core to produce parasitic currents in the bolts. Fischer-Hinnen, in investigating this matter theoretically,

was led to the conclusion that the loss was quite negligible, and Boucherot, taking examples from actual practice, found that so long as the induction in the armature iron did not exceed 10,000 to 12,000 C.G.S. the loss in the bolts was not sufficient to make it worth while insulating them. Some years ago the majority of Swiss engineers had ceased to insulate the bolts, and now the omission is universal. It must be remembered that the system of shell, clamping rings, and tightening bolts, complete, form a huge squirrel cage, an amortisseur in fact, the current in which tends to blow the field out of its domain.

The Westinghouse Company do not use for securing the segments bolts going through them, but dovetail-key them into the shell, and the Union Company, of Berlin, adopt the same plan. The sketch shows the arrangement used by the latter company. The flange cast on the shell forms one clamping ring, there being substituted for the

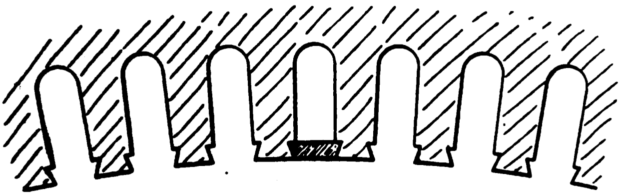


Fig. 6.

other a number of loose plates tightened up by through bolts, 2 bolts between each key. The keys sunk into the shell are kept in position by radial screws, and in the front are dovetailed to receive the plates. It should be noted that this construction permits of the building of large armatures without the use of large machine tools. The shell being laid on the floor, the feet and the joints can be slotted by portable tools, and in like manner the slots for the keys can be machined.

The armature winding of alternators nowadays consists of coils wound through holes *in situ*, or of coils former-wound and laid in open slots. Most European machines are wound according to the former method, and most American machines according to the latter. In the Paris Exhibition, though there were fine examples of both, the hole-wound certainly predominated. In plates punched

with holes it is usual to make, in addition, a cut of about $\frac{1}{8}$ in. wide, so taking away the iron at the thinnest part in order to reduce leakage, while generally in slotted plates a small notch is made on each side of the slot to admit of a wooden spline being driven under the coils to keep them in place. The sketches show the punching in the two cases. The former-wound coil can be readily replaced in the case of a burn-out, and this is of great importance in power installations when the machines are particularly liable to damage, from lightning striking the overhead lines, and where repairs have to be effected in the shortest time by a comparatively unskilled person. It has been claimed that a hole-wound coil can be replaced as quickly as a former-wound coil, but this is by no means the case unless the coil consists of a very few turns. When we come to a solid bar in each slot with end connectors, whether these

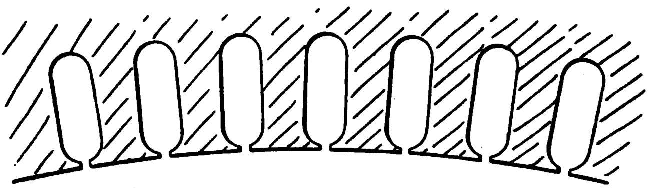


Fig. 7.

are laid in holes or slots makes no difference as regards repairs, and in such case the holes are preferable. But for machines of from 250 to 500 k.w., running at 3,000 to 5,000 volts, where the coils have many turns, the removable coils have far and away the advantage as to the time taken to effect repairs. If the coils themselves are to be as good in the replaceable form as when wound *in situ*, there is very little saving in the cost of winding. As a matter of fact they cannot then be former-wound in the same sense that a magnet coil is former-wound except for low pressure, as to make a thorough job it is necessary to wind the wires in seamless micanite tubes. Frequently we utilise at Charlton a section of the core for the coil-winding, placing the tubes in the slots, 4 or 6, as the case may be, and after winding simply knocking the coil, with the tubes on it, out of the slots.

The smallest number of slots or holes employed per pole

per phase is two, but as a rule the winding is distributed over as many slots as possible, 3 and 4 being frequently used. The spreading out of the winding reduces variation in the distribution of the magnetic field through the magnets to a minimum, while it ensures that the curve of E.M.F. shall approximate to the sine form—the ideal for all alternators. The large machines in the Moabit Station already referred to had a bar winding, there being 5 bars per pole per phase. In these the interior diameter of the armature was about 24 feet, and the current was generated at a pressure of 6,000 volts.

In three-phase machines the armature coils have necessarily to be interlaced, and the ends must be shaped in such manner that those belonging to different phases are kept well apart. There are two methods of arranging the coils which, for want of better terms, I call three-form coiling

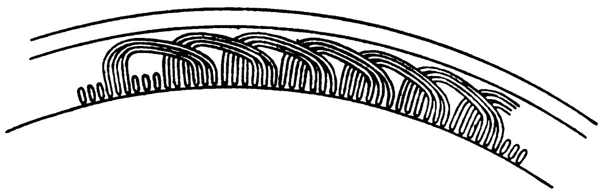


FIG. 8.

and two-form coiling respectively, and examples of both were to be seen in plenty at the Paris Exhibition. In the former there are three shapes of coil in a machine, viz., coils wound straight, coils with ends bent inwards towards the shaft, and coils with ends bent outwards. All the coils of one shape, constituting one third of the total number on the armature, belong to one phase, so that for the three phases the coils are straight, bent inwards, and bent outwards respectively. In the two-form coiling there are only two shapes of coils, those wound straight and those with their ends bent outwards, so that in each phase, constituting one third of the total, there is an equal number of straight and bent coils. In the three-form coiling, therefore, the coil ends lie in three tiers, in the two-form coiling they lie in two tiers. The latter is the more frequently used and is the simpler. When employing it there is on the armature only half the number of coils—one coil per phase to

every pair of poles—with, of course, half the number of crossings that there is in the three-form coiling, while the inwardly projecting ends of the latter are a good deal in the way.

Possibly visitors to the A. E. G. Works observed a new method of coiling for three-phase machines, in which the coil ends were twisted, but all of one form. It was intended for pressures above 3,000 volts, and the object was to get a winding in which the coil ends could be better insulated while the distance between adjacent coils, belonging to different phases, was kept nearly uniform throughout. The sketch gives a rough idea of the plan, and the winding, which is done *in situ*, is easy until the last coil is reached, when on account of the wire having to be threaded through between coils wound on each side, it is not at all easy. As Mr. Dobrowolsky naively remarked to me, a coil which breaks down is always from the winding point of view the last coil, so I am not sure that this new winding will come into use.

On the Continent the practice as regards field-magnet design, is pretty much the same as with us. In some machines the field pole and shoe consist of a block of laminated iron riveted together, which is dovetail-keyed into the fly-wheel rim. The sketch shows the method the A. E. G. adopt for keying in such blocks in the large machines at Moabit, but here the yoke ring into which the magnets are fixed is of laminated iron. The general practice is, however, to make the pole in steel with a shoe of laminated iron cast into it, a plan employed for some nine or ten years now by the Swiss engineers. Some designers are under the impression that laminated pole shoes are unnecessary when holes or partially closed slots are employed for the armature winding, and accordingly in their machines the magnet pole and shoe are made solid. My experience has led me to an opposite conclusion. Unfortunately we cannot always determine with accuracy the advantage derived from this or that modification when other slight modifications are introduced concurrently, but the results I have from time to time obtained, lead me to believe that the loss of power at full load is from 4 to 5 per cent. more with unlaminated than with laminated shoes. It must be remembered that in the allocation of the various losses in a steam alternator,

there is much that is guesswork. Suppose that perfectly reliable cards of the I.H.P. can be obtained at quarter load, it is very easy to calculate what addition should be made in respect of hysteresis and copper losses for full load. But in indicating the engines at full load we find this sometimes largely exceeded, and the difference has to be divided in some proportion between the engine and the alternator. This is where the scientific use of the imagination comes in. Undoubtedly, when it has been possible to test alternators coupled to engines, the friction law of which has been known, a very considerable loss has been shown to take place with solid poles, unaccounted for by calculation and increasing with the load. This loss may at full load amount to several times the hysteresis and eddy-current losses at no load, and it can only be due to parasitic currents in the poles. It can be almost eliminated, however, by proper lamination; of the pole shoe in any case; and of as much of the body of the pole as possible. In the Westinghouse alternators the poles are laminated throughout.

The action of the amortisseur or damping cage is well known, and a convenient way of providing for fitting it on laminated poles, is furnished by punching in the plates making up the block several holes across the pole face and close to the edge of the iron. The sketch shows five such holes, this being the arrangement adopted by the A. E. G. for all their alternators. Should circumstances arise when machines are set to work, rendering the amortisseur desirable, copper bars can be driven into the holes and joined by straps at the side to form the same. If no such circumstances arise the amortisseur bars are omitted, the holes being beneficial rather than otherwise, inasmuch as they ensure that the pole shoe is well saturated.

Some time ago I observed at a meeting of the Institution that British engineers had been putting too much material into their alternators, and I repeat this as a clear and definite statement of fact. For some reason or other, designers here had been for years the slaves of the idea that in an alternator only a very small drop in pressure between no load and full load was permissible. Trade representations that this or that alternator had a drop of only 2½ per cent. induced most designers to aim at a small drop regard-

less of the weight of material necessary to achieve the end in view, with the result, of course, that our neighbours on the Continent, who showed much better judgment in adjusting their designs to the end to be served, secured a great deal of the work. It is to be hoped that my colleagues are now mending their ways in this respect, and designing machines as do their competitors, to give say 5 or 6 per cent. drop at the full volt-ampere output with a power-factor = 1, and 30 to 35 per cent. drop with a power-factor = 0. This corresponds to from 13 to 16 per cent. for a power-factor = ·8. Incidentally it may be mentioned that a given machine carcase will give wound for two-phase just the same output as wound for three-phase with about the same drop.

Though within the limits assigned for temperature rise and efficiency, considerable latitude is allowed to the designer, I find a most remarkable agreement with respect to the value of the output-coefficient for alternators by the leading Continental makers. Taking a large number of three-phase machines, this is found to have an average value of ·015, all the fields working with an induction in the air-gap of from 7,500 to 8,000 C.G.S. High gap-induction and high field-saturation are both necessary to good design, but there are of course practical limits which have to be set to each. The stronger the main field, the less distortion will be produced in it by the armature field, and consequently the less will be the voltage drop.

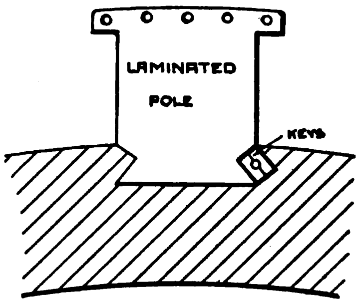


FIG. 9.

It is not my intention to trouble you at present with an investigation of the best relation of copper to iron, but it will be obvious of course that having regard to temperature rise, efficiency drop and price, there must be a *best* weight for the copper relatively to the other parts of the machine. Probably it would be found that for the armature this weight would be from 2 to 2½ per cent. of the total, and for the revolving field about 10 per cent. of the total.

TRANSFORMERS.

As in generators we have apparently settled down to one general form, so in transformers there is a tendency towards one common type. In this country the core form introduced by Messrs. Johnson & Phillips many years ago is most frequently seen, while on the Continent it is the type universally used. The peculiarity of the core transformer as distinguished from the shell transformer is that the coils are outside the iron, being slipped over the core. In the shell transformer the coils are surrounded by iron, and the core is built up of plates slipped one by one through the coils. In America shell transformers are still largely used, though there are not so many made as formerly, and the advantages of the core, as compared with the shell type, especially for power work, are now being recognised. First, the coils are outside, and, the surface being exposed, they are kept cool while running. The secondary coils, which are the easier to insulate, are placed next the iron, and the primary, in which the insulation is of relatively greater importance, are outside. By this arrangement a position where the cooling effect is greatest is secured for the high-pressure coils, a position where it is less important for the low pressure, while the iron is placed where its heating can do no harm. The transformer is therefore from the working point of view all that it should be, while the shell type is quite the reverse. Next to efficiency in working comes the question of repairs, and any one who has attempted these to both types will have no hesitation in deciding for the core. To take the iron to pieces and replace a coil in a shell transformer may be a matter of days, while in the core type slipping the yoke off and replacing a coil is a matter of hours. The flat rectangular coils used for the former are also much more trouble to rewind and more difficult of insulation than the coils used for the latter. In addition, the core transformer has a much smaller drop on an inductive load, which specially fits it for power-transmission work, which particular advantage, combined with the general advantages above mentioned, explains why the type is in universal use on the Continent. The plan adopted in America of using for three-phase work single-phase trans-

formers does not find favour on the Continent, three-phase transformers being always used. These, besides saving weight, and costing less to instal, give a better regulation where there is a likelihood of the phases being unbalanced in working. The position of the joints relatively to the coils is in core transformers a matter of importance. In three-wire single-phase working, for example, it is necessary if the two sides of the system are at all unbalanced to divide the secondary winding on both sides of the middle wire connection equally between the two limbs, otherwise good results cannot be obtained. As a matter of interest it may be observed that a transformer is always somewhat more efficient when the input is measured on the low-pressure side and the output on the high-pressure side than when the test is reversed, consequent on the eddy-current losses in the copper being in the latter case greater. From this it follows that a step-up transformer is always more efficient than a step-down one.

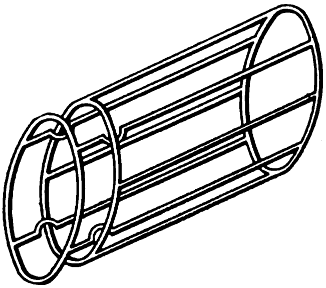


FIG. 10.

INDUCTION MOTORS.

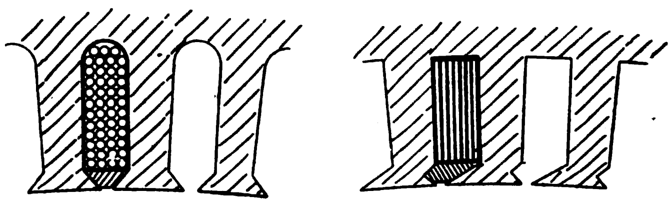
There is no specially novel feature to be recorded as regards the construction of induction motors. This subject was dealt with two years ago by Mr. Eborall in a masterly manner, and not much has occurred in the interim. I am not referring now to Mr. Heyland's latest machine which has been recently described in the Electrical Press, and which is now on its probation. Of this motor no doubt more will be heard presently; at the same time, as you are probably aware, though non-synchronous, it is not a purely induction motor. As will have been seen from Herr Lasche's paper, read in Glasgow, the A. E. G. are doing away with the outside cast-iron stator case in some of their motors, while in the particular motors used for the high-speed railway experiments the novelty is introduced of winding the rotor two-phase instead of three-phase. Whether it is intended to do away with outer

casings generally, as in the A. E. G. alternators already referred to, I am not in a position to say. At the Union Works in Berlin, curious squirrel-cage rotors for small motors might have been seen on the occasion of our visit there. Instead of having one set of bars as is usual attached to a single ring at each end, these rotors had all their bars joined at one end to a common ring, but at the other end alternate bars joined to separate rings, making virtually two sets of bars as sketch. I was puzzled to know the reason for this, but with the discovery of the designer, Dr. Neithammer, came the discovery of the reason.

In America the usual practice as regards the stator winding is to place former-wound coils in open slots; on the Continent the stator coils are always hand-wound through holes. Motors wound according to the latter method are superior from the running, but are inferior from the repair, point of view. The replacing by hand-winding of burnt-out coils in a large high-voltage motor where factory facilities are absent is a long and costly job compared with which the replacing of former-wound coils is easy. But of the superior qualities of the hand-wound machines viewed from the strictly electrical side, there can be no question, and some conversation I had with Dr. Neithammer illustrated this in a rather remarkable manner. The Union Works of Berlin started with American designs, and amongst others with open-slot stators for their induction motors. But by adopting, instead of the open slots, nearly closed slots—and, of course, hand coiling—both power-factor and efficiency have been increased, and weight and temperature-rise reduced. For small motors two methods of winding are in use, one by wire in slots, shaped as in sketch A, and one by sheet-copper strip in slots, and shaped as in B. In A the wire is not drawn through an insulating tube, but is pushed through the saw-cut at the bottom of the slot, a wood wedge being afterwards inserted under the coil to complete the insulation. Owing to the rather deep slot, the power-factor is a little lower than if there were no room required for the wedge, but the convenience of winding in this way is very great, and for low pressures the seamless insulating tube which would for high pressures prohibit its adoption is unnecessary. In B each copper strip is inserted through the saw cut at

the bottom of the slot and pushed to the right till the slot is full, a wood wedge is then inserted under the group, and the strips in all the slots are joined up by end connectors to form complete coils. Owing to the ends of the strip coils being nearer to the iron, motors so wound have a power factor of 2 to 3 per cent. less than have those with wire-wound coils, but the strip-winding being less expensive and requiring a less skilled workman than does the wire-winding, the motors can be sold at a low price.

It is the practice on the Continent to wind all rotors above, say, 5 H.P., and to introduce in circuit with the winding resistances at starting. This is unlike the practice in the States, where motors of very large powers are made with squirrel-cage rotors. The latter are provided with auto-transformers, but for starting under full torque they



A. B.

FIG. 11. FIG. 12.

require to take from the line twice the normal working current, or the full working current for half torque. Seeing that there is a large number of cases in which high starting torque is not required, and where, consequently, it is unnecessary to provide for it, it seems scarcely in accordance with the proper adjustment of means to ends to draw a hard and fast line, and say above this or that horse-power all the rotors shall be wound. My experience of large motors with squirrel-cage rotors has been in every respect satisfactory, and I regard it as mere waste of money to provide for conditions which in practice can never possibly arise. The motor ought to have a short-circuited or wound rotor according to the conditions under which it has to work.

CONVERSION.

When it is necessary to convert polyphase into continuous current, the choice lies between rotary converters and motor generators. To the subject of sub-station equipment considerable attention has been recently given, but up to the present, discussion has only served to emphasise the fact that considerable difference of opinion still exists as regards the relative merits of the two conversion methods. The rotary converter has found much favour in the States, but though its birthplace was on the Continent it is there held in considerably less esteem, while here the opinions held regarding it are very varied. Most will agree with Mr. Steinmetz's statement that while rotaries are feasible at a frequency of 60, they are perfectly satisfactory only at 25; and from this it is clear that rotaries do not admit of the adoption of nearly so flexible a system as motor-generators. The latter allow of a frequency of 50, which means that in a general system for lighting and power, continuous current may be provided for the latter where needed, the alternating current being used throughout for incandescence and arc lamps and for power where continuous current may be dispensed with.

At the Mariannenstrasse sub-station in Berlin, members had an opportunity of seeing a most interesting installation of rotary converters working at a frequency of 50 and varying in size from 1,250 H.P. to 550 H.P. Here the behaviour of the machines appeared to be very satisfactory, not the least interesting feature being the method of regulating the pressure of supply. This is done on the high-pressure side of the machine by a special booster. The latter consists of a supplementary 3-phase armature through which flows the high-pressure current, the voltage of the latter being added to accordingly as more or less excitement is given to a magnet-wheel fixed on the converter shaft and rotating inside the supplementary armature referred to. The voltage of the low-pressure feeders is by these means completely under control, and the method of effecting the whole of the regulation on a small current undoubtedly presents great advantages over the plan of regulating the pressure by heavy current boosters on the low-pressure continuous side of the converters.

But the Mariannenstrasse installation only shows that 50 frequency is feasible for rotaries, not that it is to be recommended, and the difficulty experienced in the operation of these machines at this frequency is well known. Constructionally the rotary converter is of course a compromise. It is not a good alternator and it is not a good dynamo, while at all but the lowest frequencies it combines the vices of both and has the virtues of neither. When it is remembered that the usual frequency for continuous-current machines lies between 10 and 15, it will be realised that the difficulty of designing rotaries for 50 are great; and it should be recognised that for frequencies in the vicinity of 50, motor-generators are far preferable. Quoting Steinmetz again, "when properly handled and taken care of, under reasonably fair conditions the rotary at such a frequency will do its work well; but the more you become familiar with it, the less you are confident that you can rely upon it in any emergency, and that it will not go back on you when you need it most."

It appears then that for all but purely power conversions, and often then, the motor-generator will be adopted. Mr. Steinmetz's views I have given. Herr Dobrowolsky in Germany unhesitatingly pronounces in favour of motor-generators, and so does Mr. Brown in Switzerland. Mr. Hobart recommends that they supersede rotaries for any frequency above 25; indeed every engineer who has had experience with the working of the two varieties of plant, with whom I have talked, would prefer to use motor-generators.

As to difference in efficiency and cost between the two classes of machinery there is little to choose. In his Glasgow paper Mr. Field gave particulars of cost for both equipments, inclusive of all the accessory apparatus. With regard to efficiency, so far as can be ascertained from a mass of rather conflicting statements, the rotary has the advantage over the motor-generator to the extent of from 3 to 4 per cent. at full load, and from $4\frac{1}{2}$ to 6 per cent. at half load. This appears to be the only point on which the rotary scores over the motor-generator; for parallel running, regulation and simplicity in working, the latter scores.

In writing the foregoing I had in mind synchronous

motors; I would like now to refer briefly to induction motors as applied to motor-generators. There seems to be an idea that induction or non-synchronous motor-generators are unsuitable for work of large magnitude. This cannot be on account of mere size, as motors up to 1,000 H.P. are working most successfully, and there is no reason why larger ones should not be built if wanted. Mechanically, induction motors are on a par with synchronous motors; they offer no difficulties in construction, while the driving of generators furnishes for them an ideal load. There is no doubt that the sub-station manipulation of non-synchronous motor-generators is simplicity itself as compared with that required for synchronous motor-generators, while in the former there is an entire absence of the tendency to "go back on you" which to a certain extent must characterise the working of all synchronous machinery. I have never met an engineer who does not prefer to work with non-synchronous rather than with synchronous plant, and the induction motor is so thoroughly satisfactory on all points as a machine, that every effort should be made to minimise the effect of, or cure, its one solitary electrical failing.

In the last sentence I refer, of course, to the idle current which must flow in the system due to the power-factor being less than unity, though this does not seem to have nearly such a pernicious effect as has been represented. In the first place, it must be remembered that motors running in a sub-station have a high power-factor as compared with motors of mixed sizes, some full and some partially loaded, running on a general polyphase system of supply. In the latter case the power-factor will be from ·6 to ·7, while in the former, owing to gradually improved design, it may be over ·9. In an article in the *Electrical World* of New York, Mr. Mershon asserts that recent requirements of a full load power-factor of ·92 have been met, while a power-factor as high as ·96 has been realised. Now it is a mistake to suppose that for a synchronous motor the power-factor is always—perhaps I should say is ever—unity. It depends upon the field excitement and upon the adjustment of the E.M.F. curve of the motors to that of the generators. I have found great difference in the power-factor of a motor accordingly as it is put on the Blackheath Supply Company's

mains or our own mains at Charlton, and in the synchronous motor of a motor-generator it may easily be below ·95. My contention is that with respect to synchronous *versus* non-synchronous motors for sub-stations, this matter has in some instances been decided too hastily, since reflection would have shown that the inherent simplicity of the non-synchronous motor, coupled with its extreme reliability, would have more than compensated for a possibly slightly lower power-factor.

The power-factor in the generating station may be higher than the power-factor of the motor-generators due to the condenser effect of underground mains. In all probability this fact will be demonstrated very clearly by and by in the case of various power schemes. In America a firm making two-phase motors supplies a couple of condensers as part and parcel of the equipment, these providing the wattless current for the motors, which consequently take a power current only from the mains. Well the underground mains are condensers ready to hand, and though they will not be able to supply all the wattless current to the motors, they may supply a good proportion of it. Suppose, for example, that 1,000 H.P. is transmitted to induction motors twenty miles away, at a pressure of 15,000 volts through a three-core cable. The wattless capacity current of the line will be about equal to the wattless induction current of the motor, and the station will consequently in this case supply power current only. In any case the capacity of the mains raises the power-factor, and if we suppose that the voltage-drop in a line having no capacity, with a power-factor of unity, were fifteen per cent, the additional drop due to the idle motor current would at the worst not exceed one and a half per cent. In a line with capacity this, as we have seen, is reduced. We cannot get rid of the capacity current; that we must have, and the best we can do is to arrange matters so that the generators do not have to supply it. Working synchronous motors in such a way as to achieve this unfortunately means increasing the "go back upon you" tendency, while induction motors take the capacity current naturally. It might pay to actually increase the capacity current for induction motors, provided the generators were not called upon to supply it. Notwithstanding

many failures, I have hopes that really reliable condensers for the purpose of supplementing capacity in such cases will yet be obtainable.

It is only in exceptional cases that real need for conversion arises. With our present equipment it is for street tramways imperative, as we have no alternating-current machinery quite suitable. But for general distribution for light and power it is unnecessary, as this can be effected equally well by polyphase currents. What is going on as regards alteration in the mode of supply in existing undertakings must be taken as no criterion, however, of what should be done were we to start *de novo*. Single-phase supply cannot be changed to 3-phase on account of mains already laid, though the change to 2-phase is easy. This change has already taken place at the Leeds, Sheffield and other stations, and no doubt many more will follow suit.

With these remarks I bring this somewhat lengthy paper to a conclusion. Referring to the last tour of the Institution, of German methods and German thoroughness much might be written, but the Visit Committee have dealt to some extent with these matters in their reports. I cannot finish, however, without acknowledging my indebtedness to Herr Dolivo-Dobrowolsky for the kindness I received at his hands while in Berlin. Every member who went on tour will acknowledge that in answering the countless questions put to him, Dobrowolsky showed his patience to be as inexhaustible as his genius.

NOTES ON THE MANUFACTURE OF LARGE DYNAMOS AND ALTERNATORS.

By ERNEST KILBURN SCOTT, Member.

Part I.—Dynamos.

In Part I. of the following paper the writer proposes to consider some of the principal details which go to make up the modern multipolar dynamo, and then, after giving data as to the sizes for given outputs, etc., to pass on to Part II., which deals in a somewhat similar manner with the design of multiphase alternators. As the ground to be covered is a very wide one, the writer hopes that readers will excuse the paper being rather disjointed.

GENERAL CONTOUR.

In these competitive days the introduction of pleasing curves into a dynamo machine is an important matter. The effect of beauty of form and finish was well exemplified at recent exhibitions where machines, otherwise well designed, failed to attract attention, because of their crude, inartistic lines, or from being badly finished and painted. In this matter of appearance the contour and construction of the yoke is perhaps the most important item. When multipolar machines were first introduced, the yoke was usually polygonal-shaped, and very ugly. Now it is the practice to make it circular, with well-rounded curves in cross-section; and it might be mentioned that the latter method has the advantage that the yoke can be swept up with a strickle and so save much pattern making. From the magnetic point of view cast steel is the best material to use, but the yoke may very well be of cast iron with the poles cast in (see Fig. 1). The extra section given by the cast iron is of advantage in giving greater stiffness, and where there is considerable variation in load, as in traction work, the magnetism of good cast iron responds more quickly than do the cheaper qualities of cast steel.[1]

[1] A kind of cast wrought iron made from melting scrap wrought iron with about 6 per cent. of aluminium to make it fluid has been much used in America, and one of the German firms employ a compound magnetic circuit made by heating wrought-iron slabs to redness and then running them round with cast iron to the exact contour required. When turned out of the sand no wrought iron is visible, and the tooling is about the same as for an ordinary casting.

It is now, however, becoming quite easy to obtain excellent magnet steel at reasonable prices and in good time, and on this account cast steel is being used for quite small machines, the poles being cast solid, with the yoke so that only pole-shoes are required to complete the circuit, as shown in Fig. 2. To remove a coil, only the pole-shoe needs to be taken off, which is much simpler than removing a heavy pole-piece. Absolute equality of material forming the magnetic circuit is one of the most important things to aim at, and for this reason the writer prefers having the poles solid with the yoke, the latter cast in *one* piece and afterwards cut through by cold saw or slotting machine to form the two halves.

Yokes are generally divided along the horizontal centre

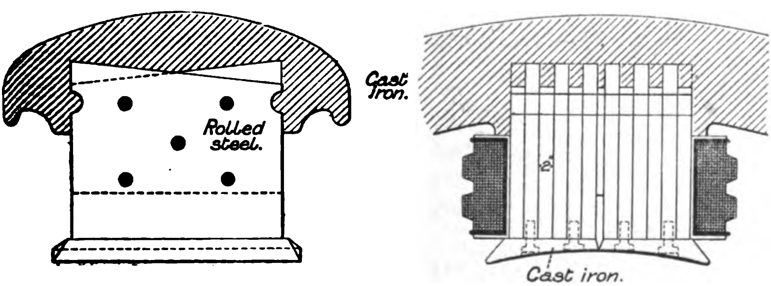


FIG. 1.

line, but some generators are divided vertically (the 1,800-k.w. Westinghouse machines at Bankside are so arranged) so that the two halves can then be withdrawn sideways for inspection of armature or field coils. There are advantages in this construction, and yet on the other hand the extra room required would appear to cut down the amount of plant which can be placed on a given ground space.

POLES.

Circular section-poles were introduced on some of the first multipolar machines made in this country, and are now much used because they give the shortest mean turn of field copper. (It is of course now generally recognised that the field-winding must be as close up to the nose of the pole as possible so as to reduce leakage and distortion of lines in the air-gap.) The modern tendency to reduce the number of armature

slots to as few as possible, calls for lamination of the pole surface to prevent undue eddy current loss. The bolting on of an entirely laminated pole is a somewhat awkward business, the method generally adopted being to build

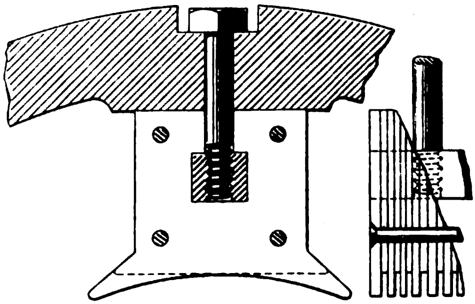


FIG. 3.—Method of Bolting Laminated Pole to Yoke.

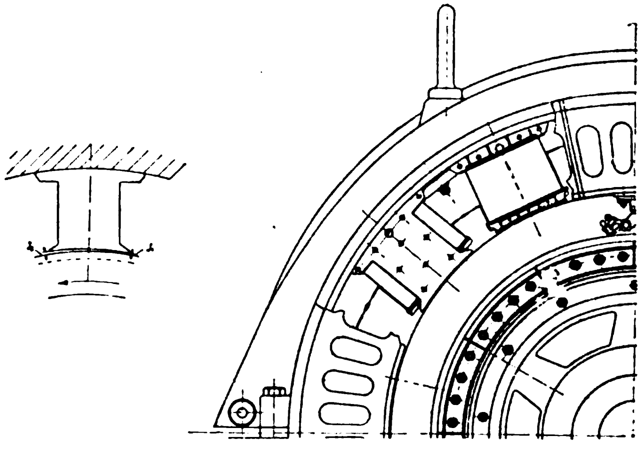
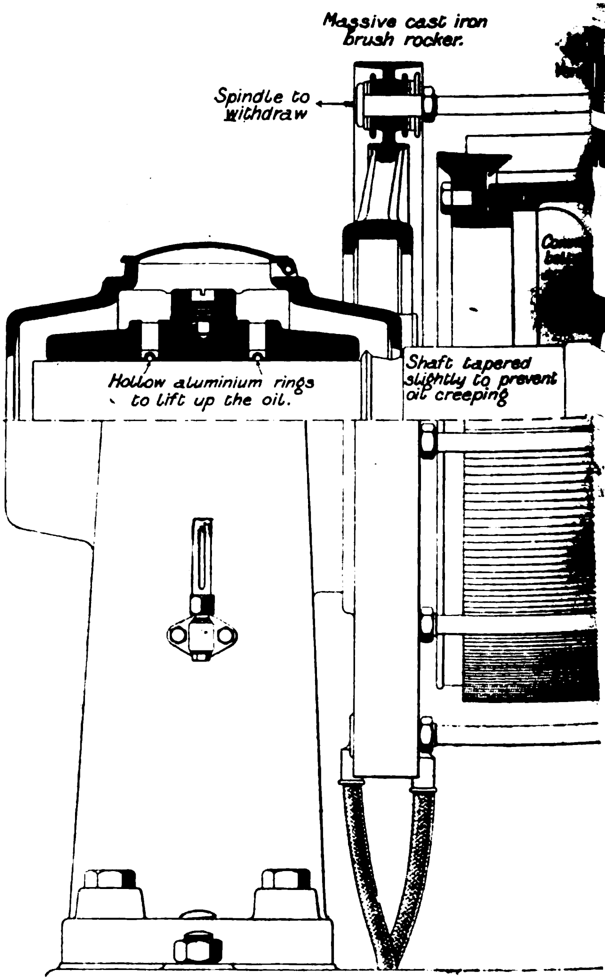


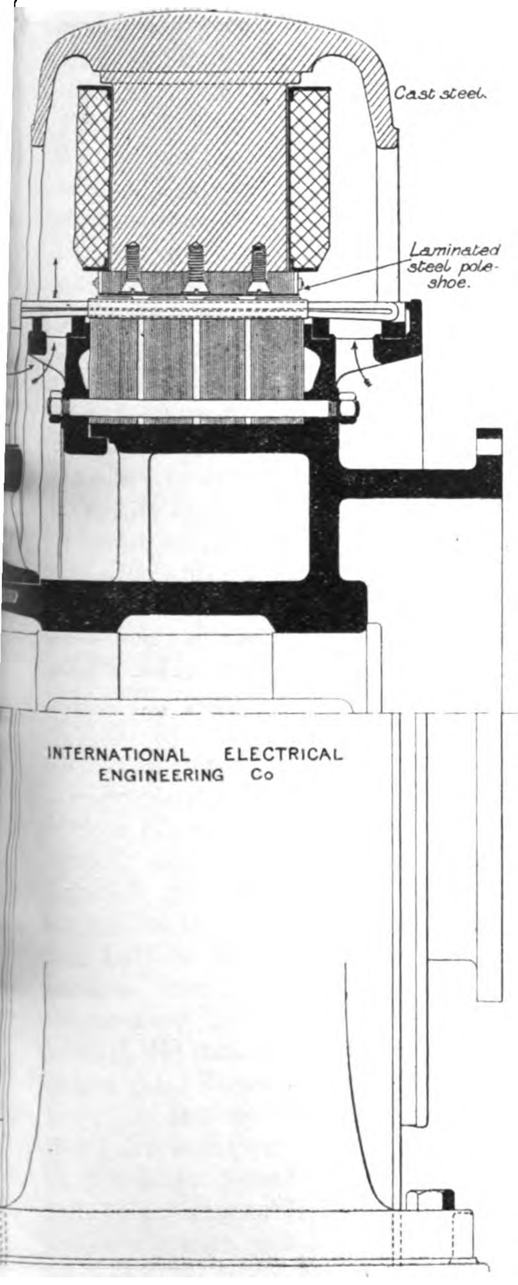
FIG. 4.—Sketch showing Method of attaching Poles to Yoke, also the unequal Air-gap of a Siemens and Halske Dynamo, 1,000 k.w., 550 volts, 95 revolutions.

up the poles round a solid steel bar, as shown in Fig. 3. The Oerlikon Co. cut a vee groove in the root of the pole, into which a double-shanked bolt is pressed. Siemens and Halske, of Vienna, have used the method shown in Fig. 4, the poles having projections where they bear against the inside of the yoke, being held in position by wedge-shaped packing pieces. As lamination is really only required at the



Massive cast iron brush rocker.
Spindle to withdraw
Hollow aluminium rings to lift up the oil.
Shaft tapered slightly to prevent oil creeping

F


Cast steel.
Laminated steel pole-shoe.
INTERNATIONAL ELECTRICAL ENGINEERING Co

air-gap, the body of the pole may just as well be solid, and this consideration has led some makers to laminate the pole-shoes only, as, for example, in Fig. 2. Such laminated shoes give reduction in area, but as a matter of fact this reduction is an advantage; the Bullock Electric Manufacturing Co., for example, purposely make their poles of very thin sheet-steel stampings cut to the shape shown in Fig. 5, so that when assembled with each alternate plate reversed the face of the pole has only one-half the area of steel. This, of course, gives a saturated pole face, and has a somewhat similar effect in preventing distortion of the field under the influence of armature reaction, as saturating the teeth of the armature core. It is therefore possible to work the teeth of the armature at a lower magnetic flux density, and the hysteresis and eddy current losses may thus be smaller.

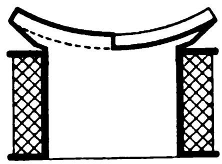


Fig. 5.

Various methods have been introduced which have for their object the partial prevention of field distortion in the gap. In one employed by the Union Electric Co. of Berlin and Johnson Lundell, the pole is slotted in the middle, one half of the polar surface being made larger than the other, so that the part of the pole with the largest surface becomes saturated. The slot is also said to reduce cross-magnetisation, but this method does not appear to be effective unless there are a number of slots made very deep.

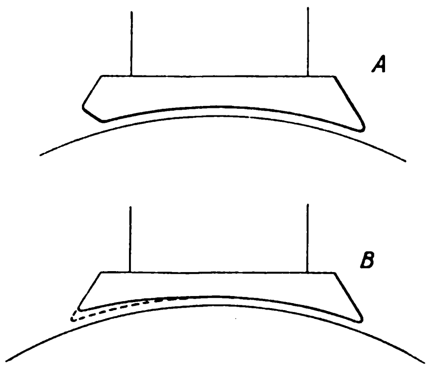


Fig. 6.

Excellent results have been obtained by making the pole tips adjustable and finding out by experiment the exact shape to suit a particular machine. These tips may very well be made of cast iron, as it is a distinct advantage to have the magnetic circuit at this point over-saturated—in fact, when a laminated pole or pole-piece is employed, it

is usual to reduce the amount of metal and give saturation by the simple device of cutting half of the plates away at the corners, as shown in Fig. 3.

Cutting the pole-pieces back at the horns which tend to strengthen, as shown at A in Fig. 6, has a distinctly beneficial effect, and was first introduced by Mr. Gisbert Kapp on some early Johnson & Phillips' multipolar machines. By carrying the idea further and shaping the polar surface away, as shown at B in Fig. 6, it is really wonderful what good results may be obtained in the direction of sparkless collection with fixed brushes.[1] In a machine, shown at the

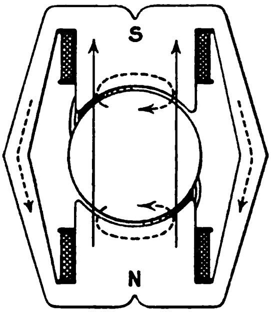


FIG. 7.

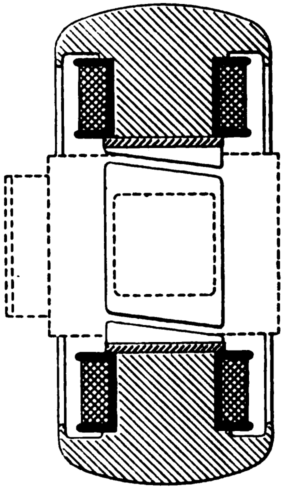


FIG. 8.—Diagonal Pole-shoes.

Paris Exhibition by the Vienna branch of Siemens and Halske, this idea was used, but the air-gap varied right across the surface of the pole, being 8 mm. at one horn, and 12 mm. at the other (see Fig. 4). This is not such good practice as shaping the pole away from one horn

[1] Referring to Fig. 7, the heavy arrows represent useful lines of force, and the curved dotted arrows the objectionable cross lines of force, set up by the current flowing in the armature. The combined effect of these two magnetic circuits is, that at one pole-horn the dotted arrows are assisting the heavy arrows, whilst at the other horn they are in opposition. Unequal distribution of magnetic lines results, and when the line density at the weakened horn falls below a certain definite amount, sparking must take place unless the brushes are pushed forward to bring them into a stronger field.

to the centre, because in the middle of the pole the air-gap should be as short as possible.

Another object in cutting back the pole tips is to enable the armature coils to enter and leave the field by a gradual transition, and naturally if the reluctance under the horns is increased, the lines are compelled to distribute themselves more gradually. Probably the best method to insure the conductors leaving a field of force and entering another gradually, is to shape the polar surfaces diagonally, as shown in Fig. 8. Both Ganz and Schuckert have adopted this method. Some firms place a thin cast-iron liner or barrel right round the armature. At first sight one might think

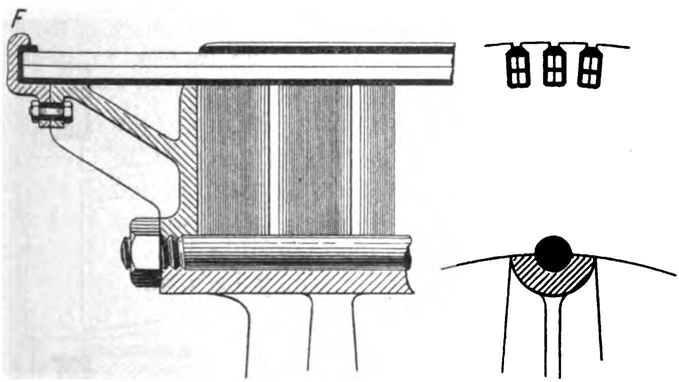


FIG. 9.

that this would short-circuit too many lines of force. It is found in practice, however, especially with the slotted form of armature, that the waste of lines of force is much more than covered by advantages gained. It gives a more equal distribution of magnetic lines in the air-gap; good support to the magnet coils; and certainty of the top half of the yoke coming down into its exact position after temporary removal. In order to keep the short-circuiting effect as low as possible, the liner should be relatively thin and made with a series of slots midway between the pole horns; the iron ribs being, of course, always saturated, leakage is not serious.

ARMATURE HUB.

A feature of recent armature hub design has been the transference of the driving stresses direct, instead of by

shaft and key. It is clear that whether the engine is of the high-speed vertical type, or the horizontal slow-speed with a heavy flywheel, it is well to transfer the turning effort to the armature-core and conductors in as direct a manner as possible. The old method of having a half coupling on the armature-shaft is, therefore, giving way to the design in Figs. 2 and 21, or in case of a dynamo built directly on the engine crankshaft, the hub is bolted up directly to the flywheel arms, as indicated in Fig. 22. In the same way it is now best practice to bolt or fix the commutator to the armature hub, and not key it separately to the shaft as heretofore. Relative movement between armature-conductors and commutator segments is thus less likely to occur.

For preventing shrinkage strains in casting the hub, the writer prefers the method shown in Fig. 22, it having the advantage over a solid boss and separated arms that the shrinking-rings assist in securing the hub to the shaft.

Rigid support should always be given to the ends of the armature-conductors by cast-iron cheeks bolted to the core, and if these castings are made as in Figs. 9, 19, and 21, the extra magnetic leakage is inappreciable. By a little care in arranging the arms, the hub may be made into a fairly efficient fan to draw air forward and pass it through the ventilating ducts.

The Armature Core.

Most armature discs are still stamped out by power presses, although the best work is undoubtedly done by cutting them off in a lathe fitted with bevelled cutting wheels, fed forward to a stop as shown in Fig. 10. Absolute concentricity of the holes and the periphery is thus ensured, and the burr can be taken off with a file as the disc revolves. By this means also any size armature disc can be made without incurring the great expense of punching tools. For example it is very convenient to be able to cut a few plates say one-eighth inch smaller in diameter for the binding wire to rest in. Again in slotted armatures, if the end core plates are unsupported, there is a tendency for them to bend over and give a very straggling appearance, besides being dangerous electrically. The best way to obviate this is to cut the stampings gradually smaller and smaller in diameter for about $\frac{3}{4}$ inch, so that the corner

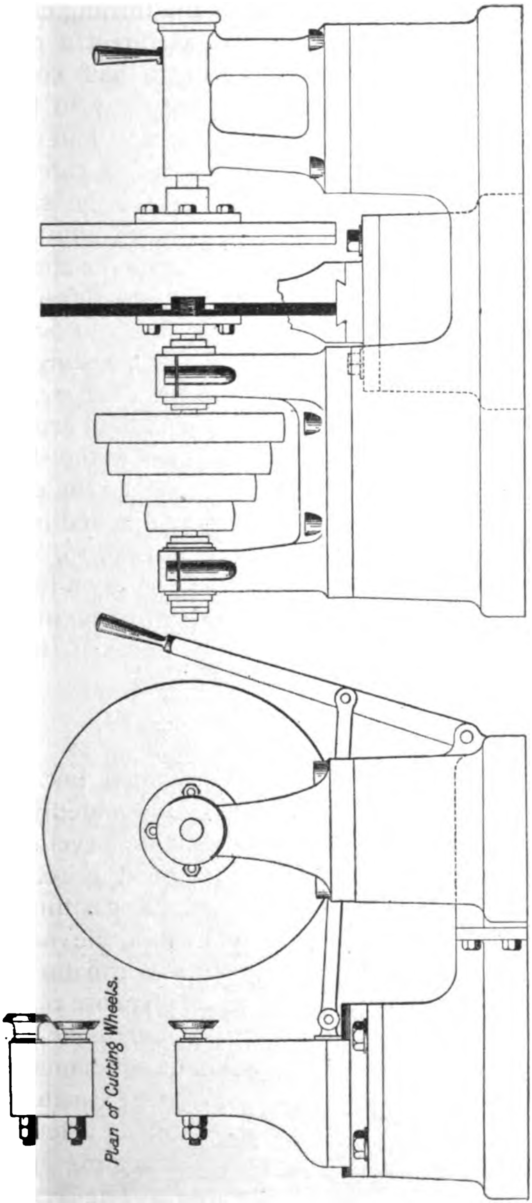


FIG. 10.—Machine for Cutting Armature Discs.

gradually rounds off to the bottom of the slot. When the plates are cut, this is easily arranged. Another reason for cutting armature core plates instead of punching them is that the latter tends to increase the hysteresis loss.

The point, at what diameter to leave off using complete discs and to begin building up in segments, is one upon which opinions are divided. The writer has known single discs to be used for armatures as large as five feet in diameter, and there is this to be said for such a practice, that the single discs are cheaper to assemble and secure.

Speaking generally, however, segments are preferable for armatures larger than say $3\frac{1}{2}$ feet in diameter, as large discs of the slotted type are liable to cockle in annealing, and set the teeth askew.

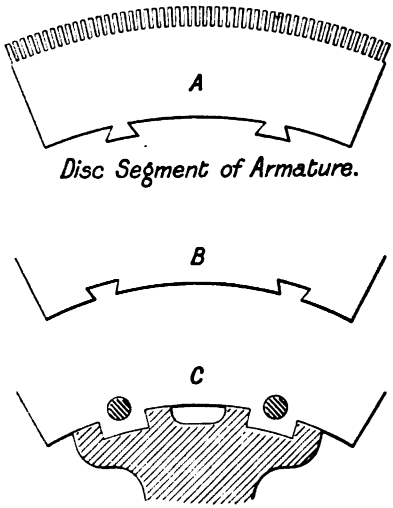


FIG. 11.—Methods of attaching Armature Segments to Hub.

Mild sheet steel, such as is used for armature stampings, is often slightly thicker in the middle than at the edge. Taken singly the difference is barely perceptible, but where many hundreds of plates are pressed together to form a core, the inequality will show itself unless care is taken in punching the discs so that when threaded on the shaft the inequality of one plate balances that of the next.

If core plates are in one piece they can be driven by steel keying bolts half in the core and half in the hub, as shown in Fig. 9, whereas segments must either be held by bolts right through the core, or else have dovetailed pieces on the inner periphery as shown at A in Fig. 11. Another method is to employ straight slots with bolts, as shown at C. American practice is to have the segments short and punch them out, teeth and all, at one blow, but on account of the labour of assembling it is just a question whether a long segment is not the best. Of course, a long

segment must necessarily be cut and held by bolts right through the core or else by vee notches on the inner periphery as shown at B in Fig. 11. Where the core plates are held by bolts it is usual to make the bolts fit tightly into the end castings. Mr. Ravenshaw has, however, adopted an endless chain construction for the 800-k.w. dynamos in the Leeds Tramway station, in that the bolts are rhymered to a tight fit in the core, but are made to clear where they pass through the end plates. The core is, therefore, like an endless chain, the bolts forming the pins of the links. Of course the core is screwed up tight, plate to plate, and is driven on the inner periphery by keys. A curious fact in connection with the wear of armature core plates is that they tend to get slack radially and not circumferentially.

Unless milled out from the solid, slots must of course be punched, and machines for this purpose have been developed which will punch as many as eight slots at a time, the feed being automatic. The burrs of the teeth are removed by an emery wheel. In some cases it is the practice to punch out the slots slightly small, and then, after building up, to clean out the grooves with a milling cutter.

Some manufacturers place great importance on the turning up of the laminated iron after it has been assembled, and this being so, not nearly so much care need be taken in punching out the plates or segments in the first instance. Slotted dynamo armatures are tackled by cutting the plates a little too large and punching out tunnels; the assembled core is then turned up, and finally the top of each tunnel is milled out and so converted into a slot. Such machining tends to burr the plates over and increase eddy current loss; the burrs may, however, be removed by treating the surface with a solution of sal-ammoniac. The passage of the air from the centre radially to the periphery of the armature is frequently provided for by inserting webbed gun-metal castings at intervals in the core. Another method is to rivet small washers to one of the side plates, whilst another consists in using a steel plate about $\frac{1}{16}$ inch, and punching small circular depressions in it say $\frac{1}{4}$ inch deep, these serving as distance pieces between the adjacent plates of the ventilating space. The teeth are held apart by punching projections in the periphery of this plate and turning them half round.

Insulation of Core Plates.

There is much difference of opinion as to how core discs should be insulated. Some advocate paper or japan, others are of opinion that the oxide coating which covers the steel during the annealing process is sufficient. It is quite certain that in time both paper and varnish tend to become powdery and drop out on account of the vibration and the constant heating and cooling, and the core loss is

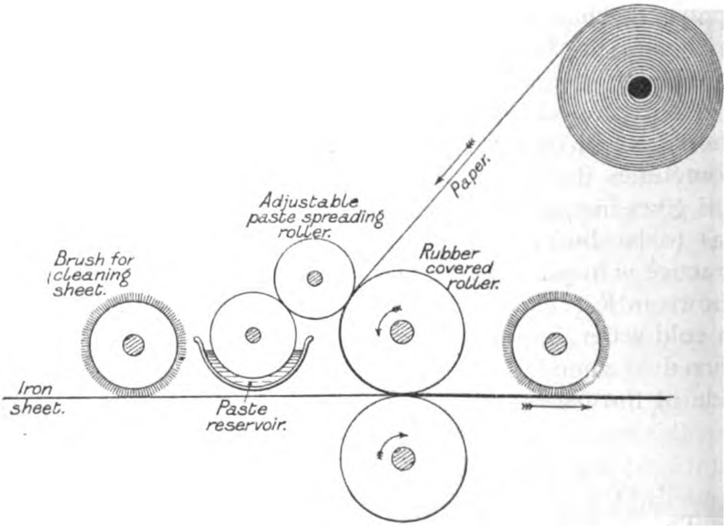


Fig. 12.—The Stolberg Paper pasting Machine.

thus liable to increase by the plates coming in contact. It has been suggested to paint the plates with a plumbago and water mixture, and then polish. Obviously the greater the nett sectional area the greater the output for a given sized carcase, and from this point of view, oxide coating is best. For plates ·014 inch thick the ratio of the nett iron section to the total cross section is about as follows :—

Insulated with paper	87	per cent.
,, ,, japan	90	,,
,, ,, oxide	93	,,

If varnish or japan is used it is advisable to dip the plates overhead in the japan and then pass them between

rubber rolls, as by this means the plates are evenly covered on both sides in one operation, and only half the total number need go through the rolls. Sometimes rollers are arranged so that the bottom one rotates in varnish, and so lays it on the plates as they go through. This is a rather cleaner operation, but it has the disadvantage that the top roller only receives its varnish from the bottom roller, and as it soon runs dry a large plate may not be evenly covered. When the plates are large they may be tackled by laying on the japan or varnish or paper pulp with a pneumatic sprayer. This method is particularly handy where there are a very large number of teeth, as the latter are very liable to be bent or torn off.

Where wood pulp paper is used as insulation the papers should not be threaded on separately, as it wastes much time. Sometimes the paper sheet is gummed to the plate, but this gives inequality of insulation, and the superfluous paper has to be burnt or punched out of the slots. The best practice is to paste the paper on to the sheet by the machine shown in Fig. 12. The paste is made from starch dissolved in cold water, boiling water being added, and the mixture stirred to a medium consistency. It is laid on the rough side of the paper.

Shape of Slot.

The best shape of slot or tunnel is not so much a question of electrical dimensions as of machining, insulating and holding the conductors in position against centrifugal force. Half-open slots, as A in Fig. 13, unfortunately cannot be used for dynamos when the usual barrel winding is employed. The writer, however, indicates below a method of getting over the difficulty. Slots B, C, D, etc., give the necessary opening space to enable solid conductors to be put in from the top. For small diameter armatures the usual practice is to have the slot parallel and to hold the conductors in position by ordinary piano wire binding carried in depressions in the core, care being taken not to solder the bands right across. In large machines, however, say of above 4 or 5 feet diameter, these bindings are not sufficiently mechanical. Sometimes broad bands of delta metal are employed, the ends being cottered together in a

neat manner. The wedge method shown in B and C is good, an objection to B being that it is rather difficult to drive the wooden wedges in from the ends, whereas in C the slot has a groove on either side for the wood to rest in, and it is therefore much more easily fitted. There is, however, the objection that the wood is not in the best position to resist pressure from centrifugal action: very cross-grained wood should be used. A parallel slot has the advantage

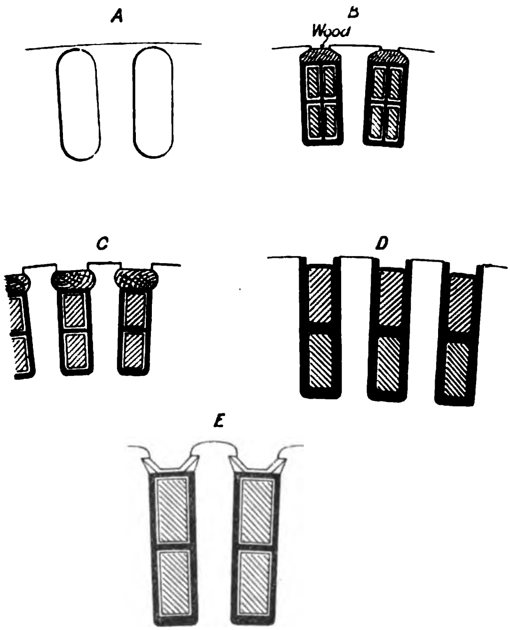


FIG. 13.

that it can be cleaned out by a milling cutter, and the winder may see much better what he is doing. The writer suggests using short buckled strips of German silver or other suitable material, as shown at E.

The simplest way to set out the width of slot and tooth is to make them about the same width at the periphery, so that the slot being parallel the tooth is rather smaller at the root. In order to guard against the teeth breaking off in handling, etc., the two corners at the bottom should be rounded out, and it is also an advantage to round off the

outer end of the tooth, as shown at E, Fig. 13, as by that means eddy currents on the pole face are reduced.

A somewhat novel slot (see Fig. 14) is used in the Bergman machines. The curvature admits of the coils being placed in position more easily, whilst the air space along the centre of the tooth increases the reluctance of the cross magnetic path.

The tendency of the future will no doubt be to follow traction motor design, and the number of slots for a given diameter of core will be much reduced. In the G.E. 800 motor for example, there were 105 slots with 6 wires in each, whereas in the more modern motor, G.E. 52 (which by the way has laminated poles) there are 29 slots with 24 wires in

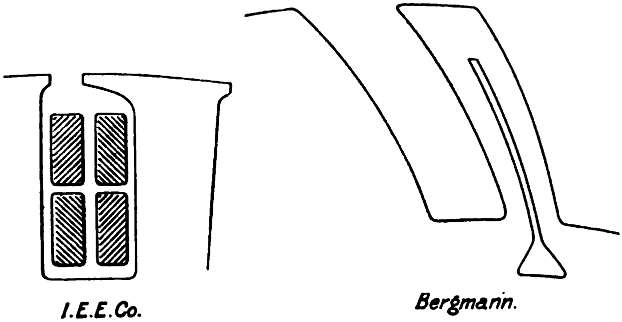


FIG. 14.

each. Ganz & Co. exhibited a machine at Paris which, by having a little care taken with the shape of the laminated pole-piece, gave good results with an unusually small number of slots for the size of the machine.[1]

WINDING OF ARMATURE.

The barrel or straight-out drum winding is now almost universal, and it may be interesting to note that it was first introduced into practical work by Parsons, on the original

[1] In the *Electrotechnische Zeitschrift*, for November 15, 1900, G. Dettmar, of Hanover, has an interesting article, in which he shows by actual experiments with iron filings, the disposition of the lines of force in the air-gap of dynamos and alternators. He gives the interesting rule that the distribution of lines takes the form of an isosceles triangle, of which the height is double the base, and from this it would appear that the partially enclosed slot, as in Figs. 13 B and 14, is the best arrangement. Clearly the effective armature surface for field magnetism should be as large as possible.

turbine sets made by Clarke, Chapman & Co. Ordinary stranded cable was used, laid in round-bottomed slots milled in the core, the cable being bent into shape at the end as it was being wound on. As the machines were two-pole, the space taken up at the ends was, of course, rather excessive. When applied to multipolar dynamos, however, the barrel winding shows to great advantage, as the larger the diameter, and the greater the number of poles, the less in proportion is the space taken up by the diagonal end connections.

When the conductor is small in section the coils may be made in one piece, the sharp bend at the corner remote

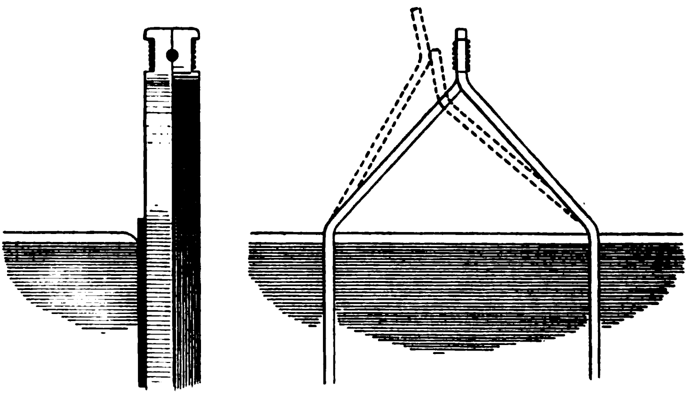


FIG. 15.

from the commutator being turned on a former, or if the conductor consists of thin strips it may be negotiated by folding the strip. Heavy section bars, where there is only one turn per segment, are generally arranged in halves. The first layer is placed in the slots with the projecting ends turned at an angle varying with the number of poles, the second layer is then placed in position, and the free ends are sweated together. More joints are thus introduced, but it makes a neat job, as it is possible to remove one of the upper bars without disturbing any other coil, whilst a lower bar can be removed without disturbing more than one half as many coils as would be necessary with the complete coil made in one piece. This is an important matter, because removing coils after they have been running some time is

very likely to crack their insulation, and cause further trouble. With series armature winding half coils are particularly convenient.

It may be mentioned that the joints will give trouble if not carefully made, as a very slight movement circumferentially causes one bar to ride over the other, as shown dotted in Fig. 15. To prevent this the writer has suggested keying the conductors together by drilling a hole in the joint, and filling with a plug of solder or harder material.

So much harm is done to insulation by the continual tapping with mallets that the writer thinks it would be well worth while to bend the conductors by means of levers shod with rollers, in much the same way as is used in shaping Thorneycroft boiler tubes. Any one who has seen the accurate and quick way in which steel tubes are bent when cold will recognise the great advantage there would be in applying the system to bending armature conductors. In Fig. 16 the writer has sketched a suitable arrangement.

It does not appear to have occurred to any one that it is quite unnecessary to bend both ends of each conductor. Clearly it would be much cheaper and more satisfactory from an insulation point of view to bend the conductor at one end only as shown in Fig. 17. In this way it could be slipped through the micanite tube from one end of the tunnel, and the present unsatisfactory wedges, piano wire bindings, etc., done away with altogether. As the micanite tube could fit tight in the slot no wedge would be required, and it will also be noticed that the micanite tube can in this case be carried right along to the end of the straight bar, only the bent portion being taped. The writer further suggests that one end of the conductors be held against centrifugal force by the end ring F, as in Fig. 9, and the other end by the upright of the commutator segment being bent over and riveted.

Internal Circulating Currents.

Exception has often been taken to the parallel-wound armature, because unless the armature is in true magnetic balance some of the circuits may generate current at a higher pressure than others, causing internal circulating currents. Unequal air-gaps or poles will also cause this.

Connecting the field coils in two parallels, those above

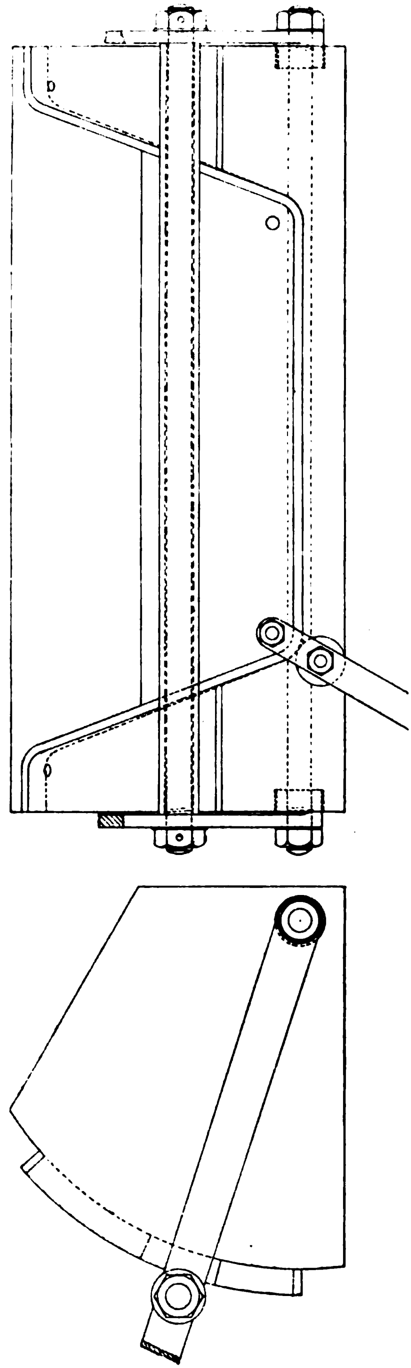


FIG. 16.—Design of Bending Block for Armature Conductors.

the spindle in series and those below the spindle in another series, enables a certain amount of adjustment to be made to counteract wear in the bearings, but great care must be taken or else unbalancing will result from the conductivities of the two halves not being equal at all temperatures.

By building the dynamo with connections as for a rotary converter, that is to say, connecting equipotential points, it is said that the unbalancing and uneven pull largely disappears. See B. G. Lammes' English patent No. 28736 of 1896.[1]

The Westinghouse Company have employed the method, but their more recent machines are provided with special conductors at the bottom of some of the slots, one end of

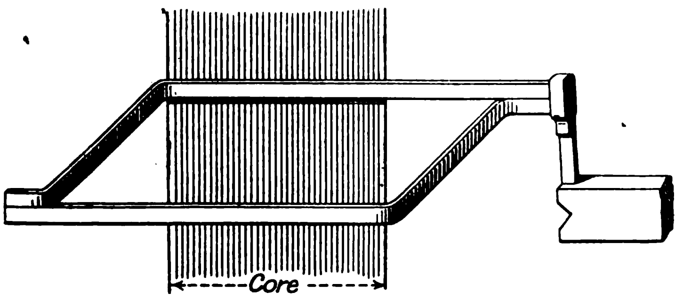


FIG. 17.—Conductors bent at one end only to pass through Tunnels.

such conductor being connected through to the commutator and the other to a short-circuiting ring, the number of such rings varying with the number of poles. These special conductors are also said to prevent surging of the magnetism in the field circuit.

The winding most generally adopted by Continental makers is that known as the Arnold series parallel winding. (See Fig. 18.) In the ordinary parallel winding it will be remembered that the numbers of slots and commutator segments must be even, whereas in the series winding the

[1] The argument is that by being cross-connected at two or three points of equal potential per pole, the winding under each pole is thus practically as in a synchronous alternating-current motor, and the cross-connections allow magnetising currents to flow from pole to pole to mutually adjust the field strength just as occurs when synchronous alternate-current machines are connected in parallel. In order to be able to do this, the number of commutator segments for a multiple circuit winding must be a multiple of the number of poles.

numbers must be odd. In the Arnold series parallel winding the slots and segments are even, the winding being a re-entrant series winding with an even number of slots and segments. In commencing at, say, a positive brush and going completely round the armature, the conductor does not arrive at the segment next to the one started from as in an ordinary series winding, but finishes at a segment

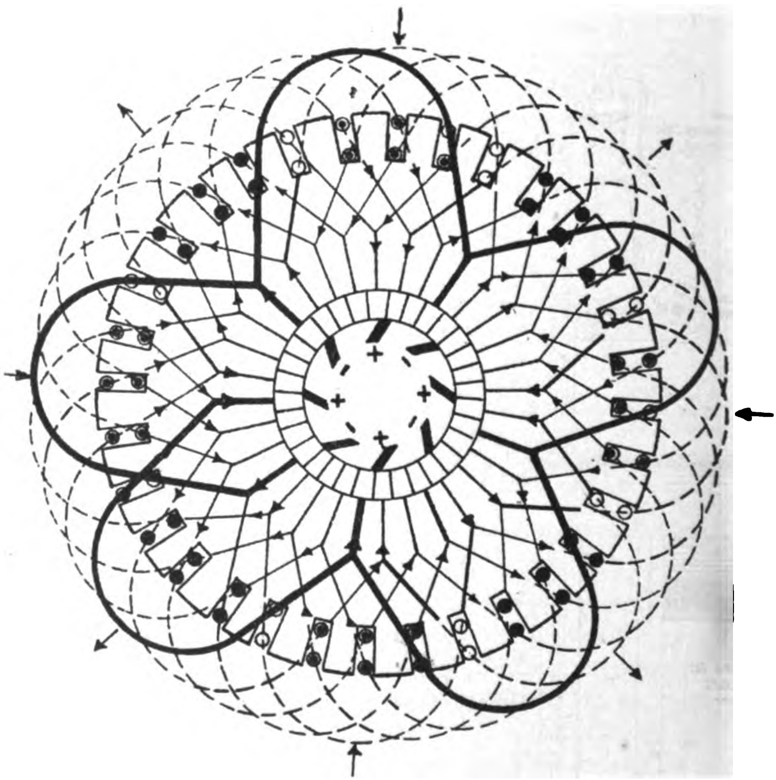


FIG. 18.—The Arnold Series Parallel Armature Winding.

somewhere near to the next negative brush. The only objection to the winding is that certain ratios must be observed between the number of poles and the number of slots; on the other hand it has the great advantage that, although a series winding, there may be as many brushes as poles, or only two sets of brushes, as in plain series winding.[1]

[1] Most of the Continental machines given in Table I. below have the Arnold winding.

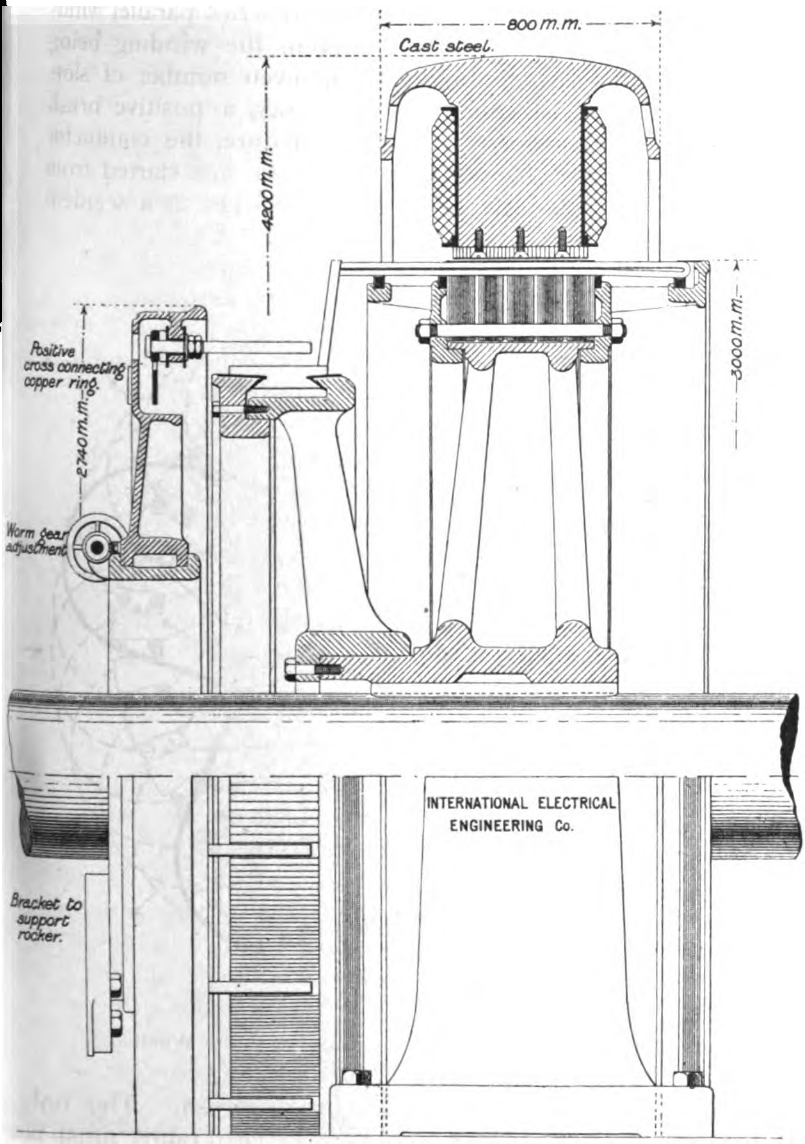


FIG. 19.—Slow-Speed Dynamo, 1,000 k.w., 85 revolutions.

Another method of equalizing the magnetic circuit is for the pole shoes to be bolted up to iron rings, all Norths to one and Souths to another. The shoes fit close to the poles, and the section of each ring bears a definite ratio

to the rest of the magnetic circuit. The brush ring is mounted on one of the pole rings, and there is an arrangement whereby the pole shoes can be adjusted in a rotary direction.

It is now a common practice in large output parallel-wound machines to keep the conductors down to a reasonable size by having two, three, four, or more circuits. This gives two or more commutator segments all at the same voltage, and the brushes span many segments instead of only covering a little more than one, as in single-wound armatures. The length of the commutator is thus decreased for a given current output. Multiplex armature winding, as it is called, practically changes an unwieldy conductor into several smaller conductors, and the eddy current loss is reduced. As the commutator bars of one winding are not adjacent to each other, but alternate with the bars of the other windings, there is not so much risk of a section being short-circuited. Multiplex winding is especially useful where a dynamo is built for 230 volts and requires altering afterwards to 460 volts, whilst for very large outputs the method becomes a necessity on account of commutation.

Commutators.

If commutators are not provided with a solid support on the inner side of the segments a blow on the surface may produce a flat. The trouble arises partly from the difficulty there is in getting metal segments and mica strips exactly to gauge, and also because when the parts are clamped together and the inner surface bored out it is hit or miss whether the segments fit tightly on to the insulation. The skill of the workmen enters largely into successful commutator construction.

Undoubtedly the best way of holding commutator segments is by vee-shaped micanite rings, which are now readily obtainable in standard sizes. For the mica between segments, continuous strips are better than built-up mica, for one reason because in building up the latter there is danger of getting conducting particles in between the laminations. Of the many qualities, only soft amber mica is suitable for strips, which are cut from the solid, as at the usual thickness of ·035 of an inch, experience shows that

amber mica wears down at about the same rate as hard-rolled or drop-forged copper. Built-up mica wears down more quickly, and therefore the many varieties of harder mica may be used in its construction.

Much trouble has been caused by the commutator lugs snapping off short at the commutator bar, and in order to insure against this it is now usual to key the commutator as a whole on to a projection of the armature hub so as to

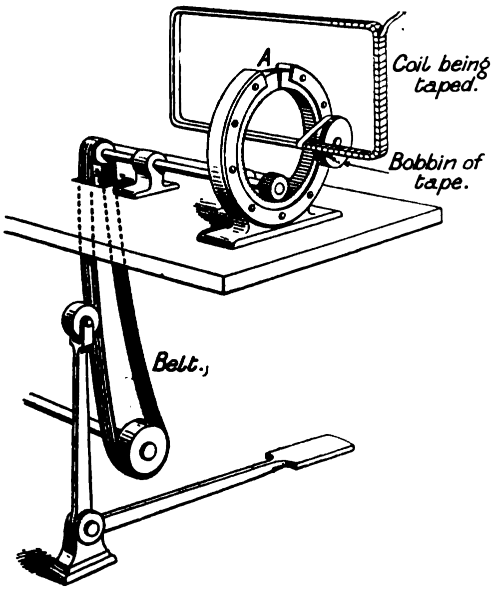


FIG. 20.—Machine for Taping Closed Coils.

prevent them moving relatively, expansion of the lug being also provided for by slightly buckling it midway in its length. In some cases where dynamos have been driven by high-speed steam engines, the breaking of commutator lugs has been traced to a periodical vibration set up by the cranks, the armature, and the barring flywheel; in fact, it was this which led Messrs. Willans and Robinson to insist on the barring wheel of their engine being bolted up direct to the armature hub, as shown in Figs. 2 and 21.

A feature of many foreign machines is that the commutator lugs are made of high resistance metal, such as German

silver, Rheotan, etc., the idea being to assist sparkless reversal. Other makers use quite small section flexible connections from the armature conductors down to the commutator segments, so introducing resistance, and also ensuring that the connections shall not be broken by vibration.

It is also becoming quite common, on the Continent especially, to fasten the armature connection to the commutator segment by means of steel grub screws and so dispense with solder. A conductor, quarter-inch diameter, will have as many as three grub screws, each half-inch in diameter, to hold it in position.

In some machines special efforts are made to keep the commutator cool. For example, the dynamos in the Luisenstrasse Station in Berlin are fitted with a small electrically driven air blast, which also removes any copper and mica dust from the armature, etc. Some of the Schuckert and Lahmeyer dynamos have slots cut right through the segments to allow air to circulate through.

Commutators for large output machines which are coupled to high-speed engines must of necessity run at very high peripheral speeds. In some such cases sparking difficulties have been experienced, but they do not, however, appear to be due to the fact that at high speeds good commutation is impossible, but to deficient mechanical design. There is no reason why dynamos of 1,000 k.w. and upwards should not be built for coupling to Belliss, Willans, or other similar engines if the commutator be built with its hub of cast steel and the commutator sections of high drawn copper made of buckled section so that the adjacent segments support each other. Such a commutator pressed up in a hydraulic wheel tyre press will be equal to anything reasonable in the way of high peripheral speed.

Brush Gear.

The question of the design of carbon brush holders presents quite a little problem in itself, but as it has been dealt with at considerable length elsewhere (see Parshall and Hobart's "Electric Generators," Fischer-Hinnen's "Continuous Current Dynamos," the writer's articles in the *Electrical Review*, April 22 and May 6, 1898, etc.), it will

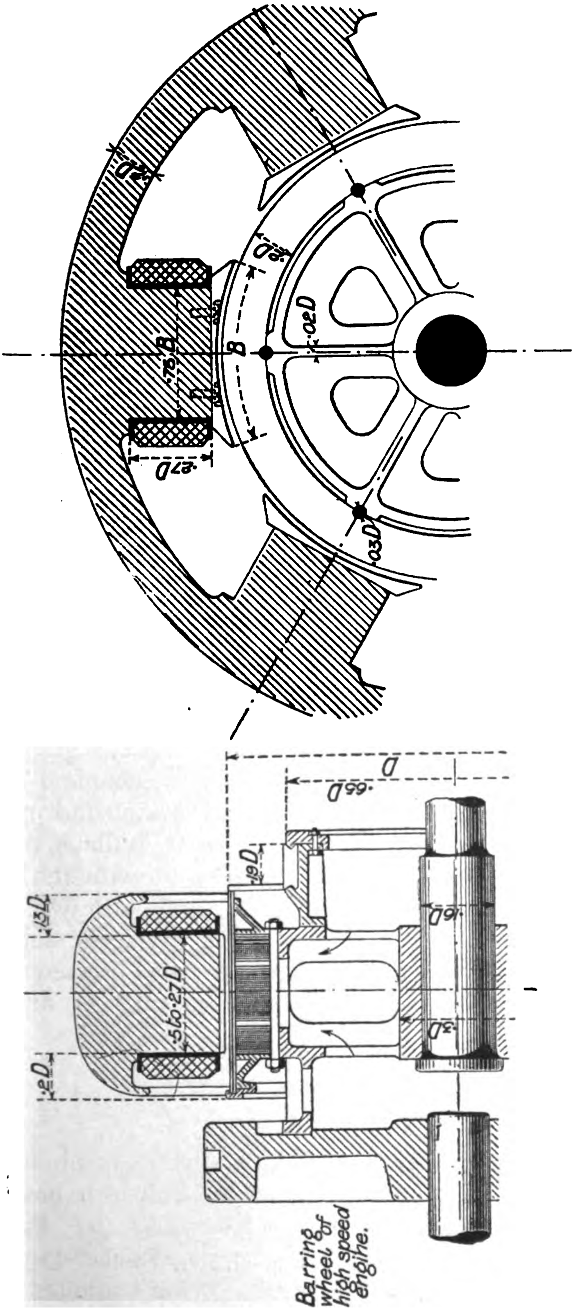


FIG. 21.—Approximate Proportions of a Multipolar Dynamo suitable for Coupling to a High-speed Engine.

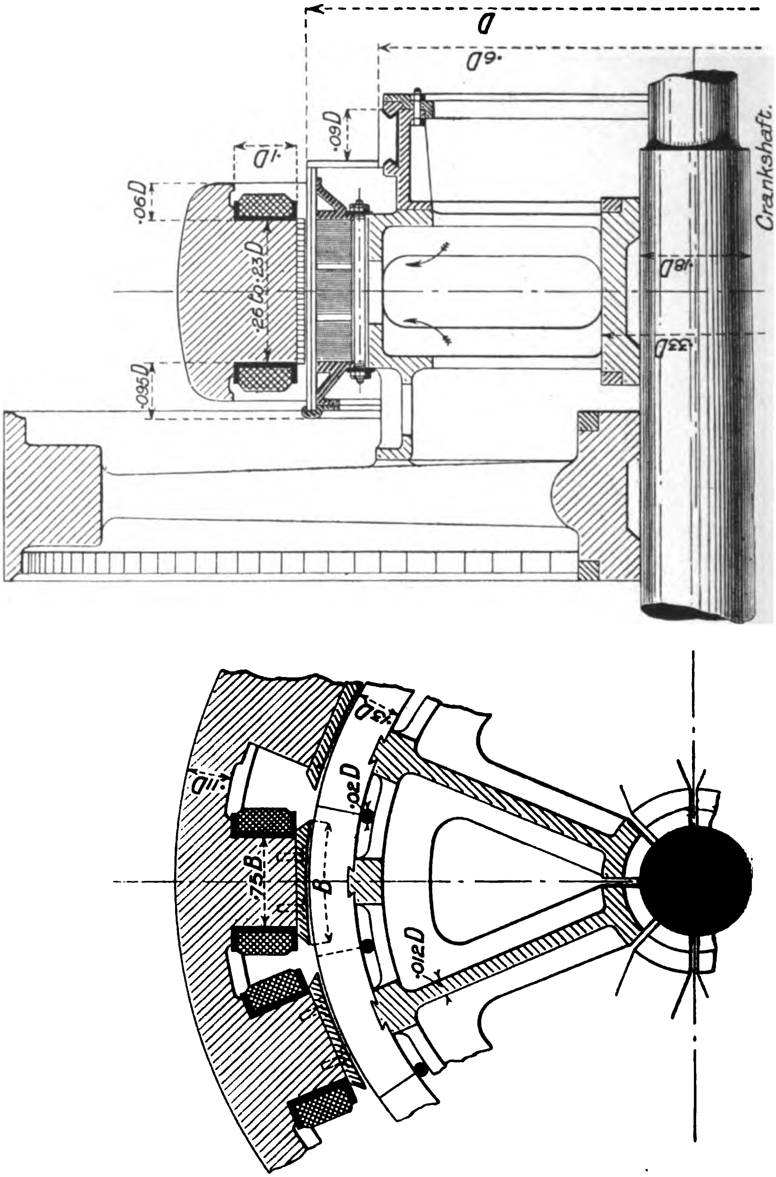


FIG. 22.—Approximate Proportions of a Flywheel Dynamo.

be only necessary to summarise here some of the points which the writer's experience has shown to be essential to a good brush holder :—

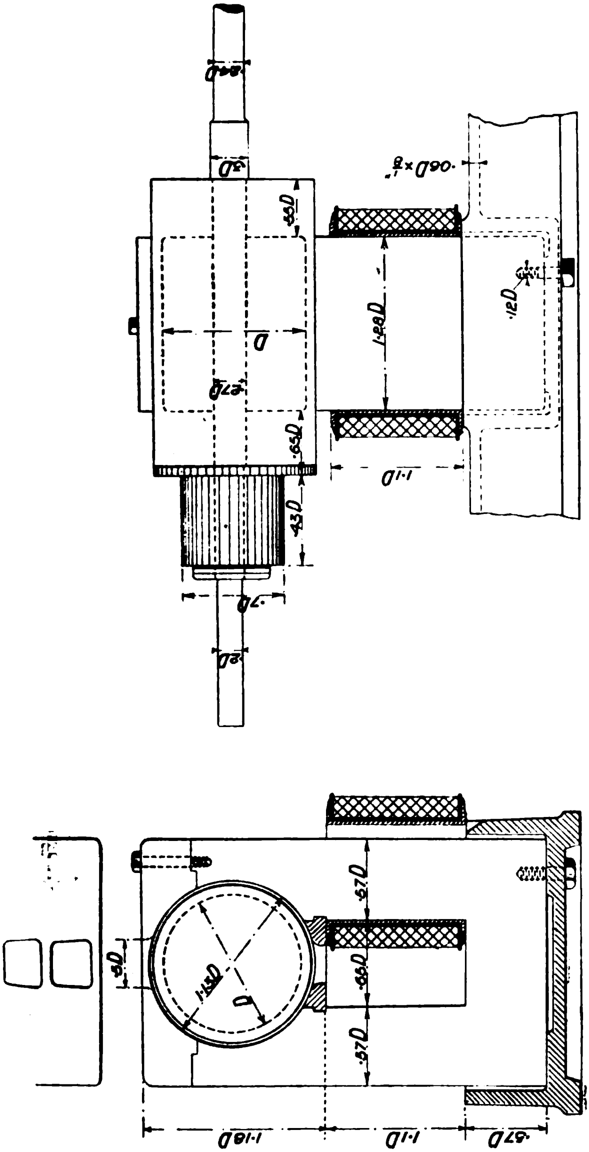


Fig. 23.—Approximate Proportions of a Bipolar Dynamo.

(*a*) The carbon block *firmly fixed* at the end of a fairly long arm.

(*b*) The inertia of the moving parts reduced as much

as possible. This may be effected by constructing the holder of aluminium or sheet metal.

(*c*) Current taken from the carbons by short pieces of flexible soldered direct into the blocks.

Some makers arrange the carbon blocks exactly square to a whole number of segments, and many prefer loose carbons pressed down by a spring finger. These do very well for traction motor work, but for dynamos the number of separate blocks becomes considerable, and the chatter and noise of loose carbons is too great, even when they are of the ingenious reaction type. There is always a considerable drop of volts with carbon brushes, and where efficiency is a prime consideration, as in a dynamo, the current must be carried as direct as possible to the main terminals by flexibles soldered direct into the carbons.

A favourite method of carrying the circular brush rocker is by means of four or more arms bolted to the yoke, but the writer does not like this method for the following reasons: If the arms are brought to the outer end of the commutator they cover up the brushes at various points, whilst if the arms are brought down to the middle or to the inner end of the commutator much space is uselessly occupied. Again, in case the yoke has to be racked sideways or the top half removed, then the whole of the brush gear must be unshipped. Where it can be conveniently arranged the writer considers that the brush rocker should be carried from a bracket bolted to the bearing casting, as shown in Figs. 2 and 19.

Brush rocker rings and the attachments of the spindles, etc., are often too weak in design. Being the only part of a dynamo which the station attendants have to handle, everything about it should be massive, and yet at the same time the fitting and design such that the brush adjusting gear can be worked without appreciable effort.

Fig. 19 indicates this massive construction, and a neat feature is the boxing in of the ends of the brush holder spindles and connections, as well as the two heavy copper rings connecting the positive and negative sets of brushes respectively.

A feature which many dynamos lack, is an arrangement by which the attendant may raise and depress the brushes

all together. At a certain station, for example, there is an 1800-kilowatt dynamo with 20 poles and 9 separate brush holders to each, which makes 180 brushes in all—many of them in an inconvenient position. To ask the dynamo attendant to lift all these brushes separately is rather too much, and makers would no doubt find it well worth while to add the small extra piece of gearing required. It is easily arranged by means of bell crank levers at the ends of the brush spindles.

Electrical Insulation.

For insulating armature slots some makers use layers of press-spahn (a red coloured pure wood fibre paper finished

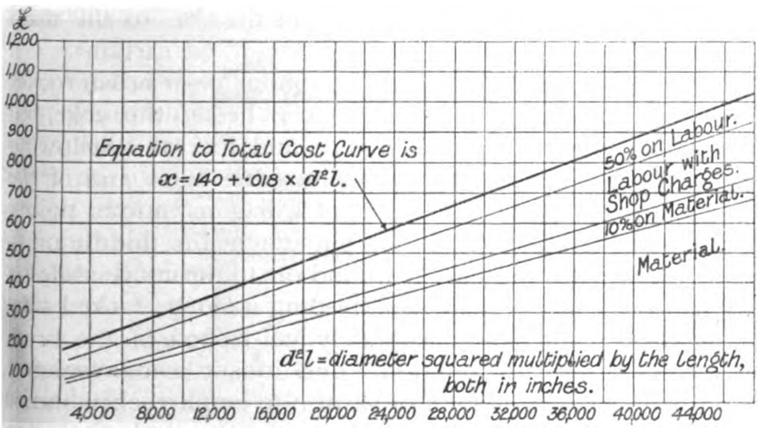


FIG. 24.—Cost of Dynamos suitable for Direct-coupling to Engine. No Bed-plates.

with an oily glaze), whilst others employ micanite troughs or tubes made to the exact size required. Many manufacturers use press-spahn, micanite, and oiled linen, and one firm mills out the slots full large and then lines them with strips of teak wood. Press-spahn is a very superior insulation if it is kept dry, the writer having flashed Siemens armatures at 7,000 volts which had the slots insulated with this material alone. It is risky to depend on it altogether, however; mica in some form or another should be employed. Mica has one advantage over all other forms of insulation in that it has exceedingly high disruptive strength, and is not affected by atmospheric conditions. Great care must, however, be

taken in selecting and making up the mica. The writer is of opinion that the best results can only be secured by the dynamo manufacturers making their own micanite and other insulation.

As micanite channels or tubes only protect the conductors where they pass through the core, it is necessary to use cotton covering or tape, etc., elsewhere. For large conductors taping is essential, and it is usual to tape over double cotton covering. It is good practice to use plain cotton tape and serve with varnish after it has been wound on, because the various adhesive tapes are so awkward to handle. They also lack mechanical strength and generally contain a fair amount of moisture. The shellac should be made with best alcohol; wood alcohol is of no use. The baking must be done thoroughly, or the alcohol will attack the copper.

Taping formed coils or bent conductors by hand is an exceedingly tedious process. It can be done much more quickly and neatly by machinery, and Fig. 20 illustrates a suitable machine. The coil is introduced into the centre of the revolving ring by means of a diagonal notch, and the bobbin of tape is carried on a pin attached to this ring. As the ring rotates the tape is wound on to the conductor, and a pair of rollers grip the coil, feeding it along at the proper rate, so that the tape is accurately half-lapped.

One of the most important questions in connection with insulation is—what kind of varnish to employ. Shellac has been most used, but the quality varies so much that other special varnishes and paints, etc., are now employed.

The Monarch Asphalt Paint and the P and B Compound are used in America, whilst a fair number of makers are adopting pure linseed oil. Although it has not very great disruptive strength, or high insulating resistance, it is found that when oxidised at the proper temperature to expel moisture, linseed oil is very reliable. It is practically non-absorptive and is only affected by a temperature far higher than that which destroys the cotton insulation into which it is soaked. Cotton which has been shellac-varnished becomes brittle, whereas when oil is used it remains flexible. Only pure linseed oil should be used, and care must be taken to lay it on very evenly. Of course, for winding magnet coils the double cotton-covered wire may be run through hot

paraffin immediately before it is wound on ; or the writer suggests placing a number of coils in a vacuum oven, and as soon as all moisture is driven off, flushing them with boiled resin oil in the same way that cables are treated.

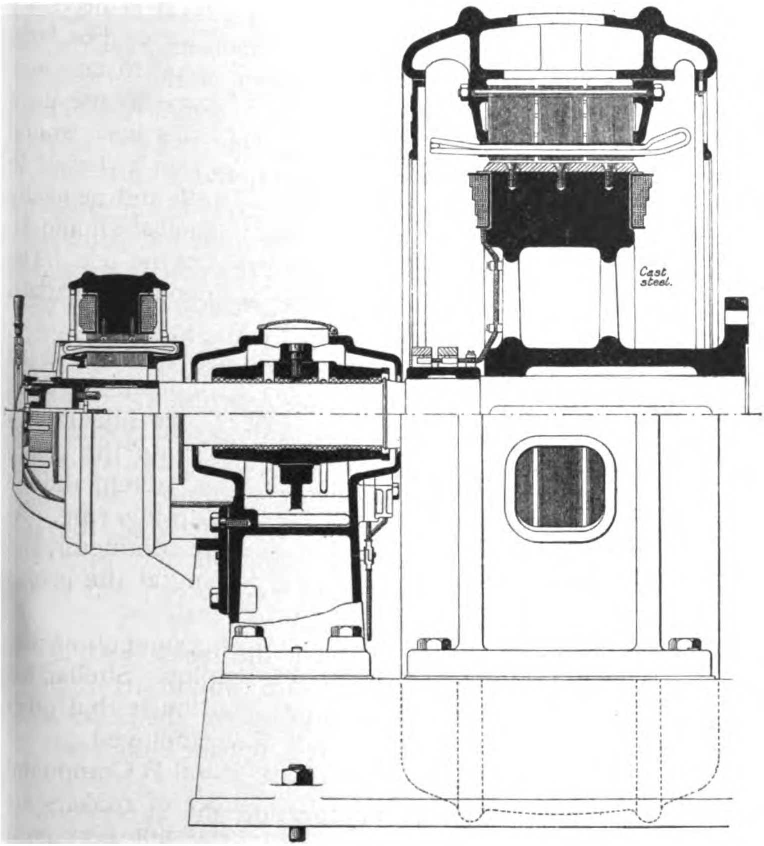


FIG. 25. Multiphase Alternator (I.E.E. Co.) for Coupling to High-speed Engine, as supplied to Erith U.D.C.

An easy way to varnish an armature is to pour the varnish, armalac, or whatever is used, into a shallow bath, and support the armature in journals, so that its periphery just dips into the liquid. By revolving slowly, brushes can be dispensed with altogether.

Some day, possibly, a cheap compound will be discovered which will not soften or get brittle when the

armature warms up, and into which the armature can be dipped overhead in much the same way that a transformer is dipped in ozokerite or diatrine.

FIELD WINDING.

In very large overcompounded machines, such as are used in traction work, the sectional area of the series winding is considerable, and it is often a somewhat difficult matter to arrange it conveniently. One method employs ordinary stranded cable—61/11, 91/11, and so on—according to the current to be carried, the coils being supported from the magnet yoke so that they are quite independent of the shunt coils. Where the section of the pole is circular or oval, bare copper strip of slightly taper section may be wound on edge in the manner introduced by Mr. Ferranti, the insulation being by discs of rice paper or presspahn. An objection to this method is that the copper cannot be unwound and used again, as is the case with ordinary flat tape. Another method applicable to rectangular poles is to wind on a flat copper ribbon of the full area required, and rather less than half the width between the flanges of the field magnet former. A broad sheet of longcloth and mica insulation a little wider than the copper is wound on with it, and there are thus two turns per layer.

In order to avoid bringing out the inside end of the field magnet coil, two sections are wound in opposite directions, so that when placed side by side the inside ends are connected together, and the free outside ends form the terminals.

To save expense and complication the compounding turns may very conveniently be carried round the north poles only.

There is not much to say regarding shunt windings, except that in large machines it frequently happens that a standard gauge of wire does not give the correct ampere turns. The usual practice in such cases is to employ the next two sizes of wire, large and small, and adjust the turns of each until the required current is obtained. As it is exceedingly important that each pole must have the *same magnetic strength,* it is necessary to be careful to get just the right quantity of each size of wire on each pole. On this

account, and also because of the joint required, it is good practice to take the next larger wire and draw down to the exact diameter necessary. The equipment of an up-to-date dynamo works is certainly not complete without wiredrawing, cotton covering, braiding, and taping machines.

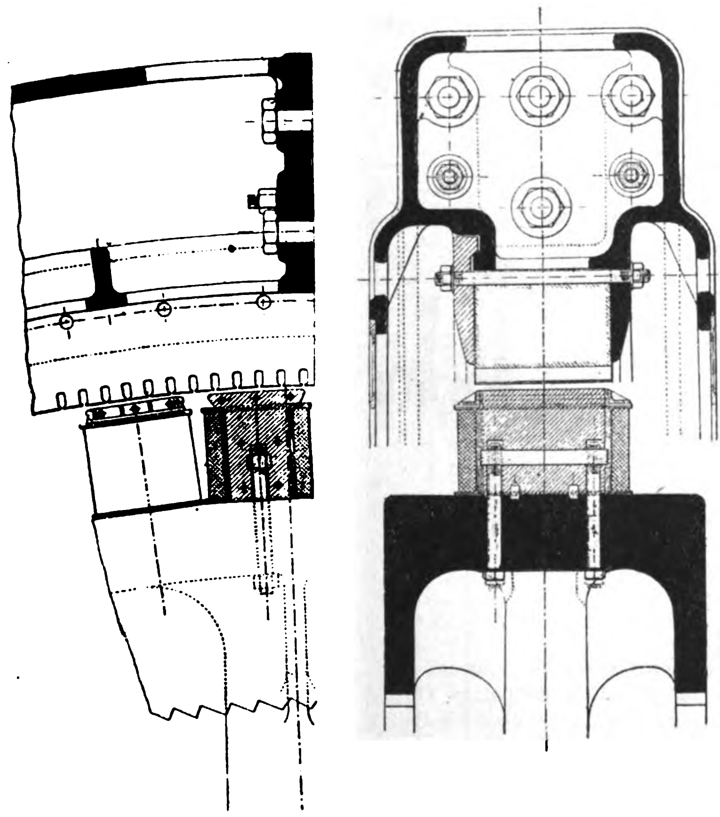


Fig. 26.—Three-phase Alternator by Compagnie de Fives-Lille. Output 800 k.w., 2,200 volts, 50 cycles, 79 revolutions, 76 poles. Diameter over Poles 235 inches, giving Peripheral Speed of 4,850 feet per minute. Air-gap 0·275 inches. Diameter of Shaft 25 inch.

The energy stored in the magnetic circuits of large dynamos is so very considerable that it is always as well to make a short-circuiting shunt break switch part of the machine, so as to ensure that it shall be always used. At the same time the insulation of the coils should be flashed with a pressure at least five times the normal voltage.

Magnets may be surrounded by a sheet of brass, copper, or zinc, forming part of the spool, as it is noticed that such an arrangement reduces the flash on breaking circuit. There is also an old dodge in telegraphic instrument making, which has for its object the reduction of the self-induction spark. It is to wind the layers *always in the same* direction, instead of backwards and forwards.

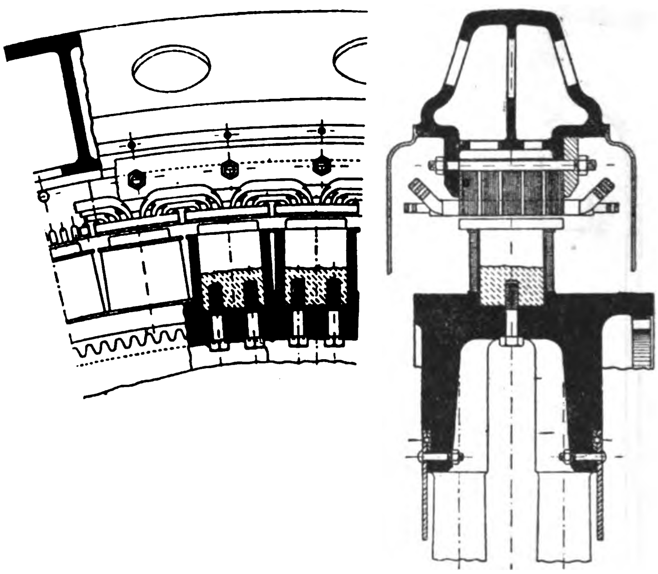


FIG. 27.—Three-phase and Single-phase Alternator by the Helios Elektricitäts A.G. Output as Three-phase 3,000 k.w., and as Single-phase 2,000 k.w., or if giving both together the Outputs are 1,500 k.w. and 1,200 k.w. respectively. Voltages 6·600/3,300/2,200, 50 cycles, 71·5 revolutions, 84 poles. Diameter over Poles 315 inches, giving Peripheral Speed of 5,900 feet per minute. Air-gap 0·47 inch. Diameter of Shaft 23·7 inches.

This has also the advantage that the thread is always the same, and so the layers pack better.

BAKING.

Baking is one of the most important operations. If an oven is employed it should be very spacious and well-lighted, with several small iron doors fitted into the large doors. There should be trolley lines, so that the heavier armatures, etc., can be run in and left on the trolley, for

when anything heavy has to be handled in a hot room it is apt to be knocked about. The temperature should be about 170° F., but for anything special 200° F. to 300° F.

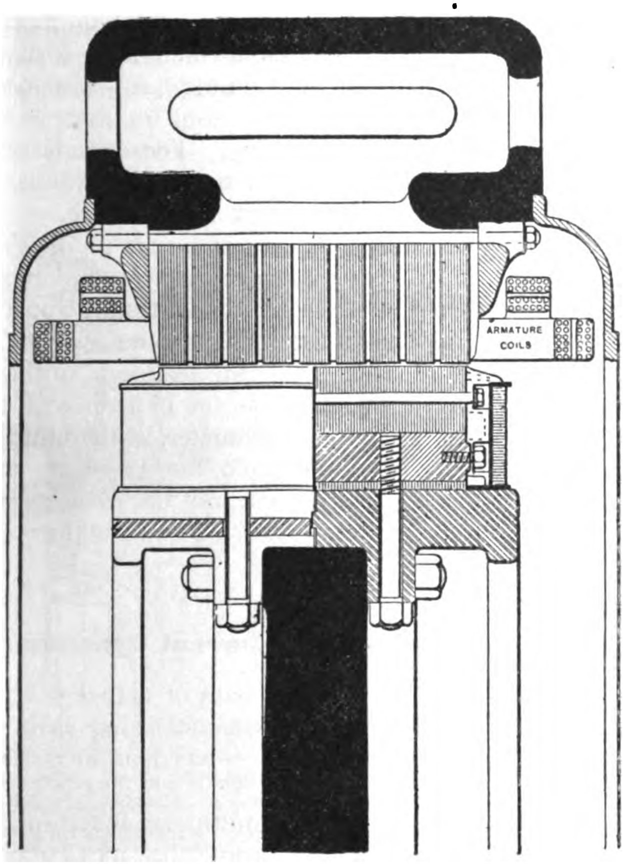


FIG. 28.—Three-phase Alternator by G.E. Co. of America for the Metropolitan Street Railway Company of New York. Output 3,500 k.w. (5,000 k.w. for 4 hours), 6·600 volts, 25 cycles, 75 revolutions, 40 poles. Diameter over Poles 200 inches, giving Peripheral Speed of 3,900 feet per minute. Air-gap 0·312 inch. Diameter of Shaft (hollow) 37 inches.

is useful. Foundry core ovens are sometimes used for these higher temperatures.

In certain cases, where the oven is full or the apparatus to be dried is unwieldy, moisture can be driven off by passing through it a large current at a low voltage, surrounding the coils with asbestos board to localise the

heat. In this case, as the heating goes right through the coils, it is more effective than oven drying, but the electrical method is of course more expensive.

Undoubtedly a very effective method is to use a vacuum chamber. The Passburg apparatus is the best known, and it consists of a circular shell five or six feet diameter, with air-tight door and glands. A steam coil is arranged inside, space being left for one or more sets of rails to support the workshop trolley. The outside of the chamber is lagged with non-conducting composition, and the steam in the coil is at about 75 lbs. pressure.

The accessory apparatus consists of an air pump giving a vacuum of 20 in. to 29 in., a small surface condenser to take up any moisture drawn off, and also a testing apparatus to indicate when all the moisture has come away. This apparatus has been adopted by all the leading Continental firms, some firms having as many as ten or twelve in their works. An apparatus five feet diameter, with pump and condenser complete, costs about £260, but there are many advantages to be derived from its use, not the least of which is that an armature or coil may be dried in a fraction of the time that it would take in an oven.

Tables, etc.—Continuous-Current Dynamos.

A very considerable amount of data of actual machines is now available, and with a view to crystallising as it were many of the particulars, the writer has compiled Tables I. to VIII.

Table I. gives data of various multipolar machines, and Table II. coefficients deduced from the particulars in Table I., the figures being given in English measures. Table III. gives coefficients deduced from data given in Professor Arnold's book on Armature Windings.

In settling the preliminary dimensions of any dynamo the two leading dimensions are the overall diameter of the armature in inches d and the overall length of the armature core in inches l. From these we can obtain various useful figures. The first, which may be called the "*size constant*," is obtained by multiplying the diameter squared by the length of the core

$$(d^2 l).$$

In the second (due to Steinmetz) the diameter, multiplied by the length and divided by kilowatts, gives a coefficient $\left(\frac{d \times l}{\text{K.W.}} = \text{coefficient}\right)$ which varies according to the size of machine. See the 9th column in Table II. and the 10th column in Table III. It may be taken as ranging from 2 for the largest flywheel generators up to 8 for the smaller sizes of multipolar machines, but as will be seen from Table II., a dynamo by Siemens Bros. and Co. gives the unusually low figure of 1·4.

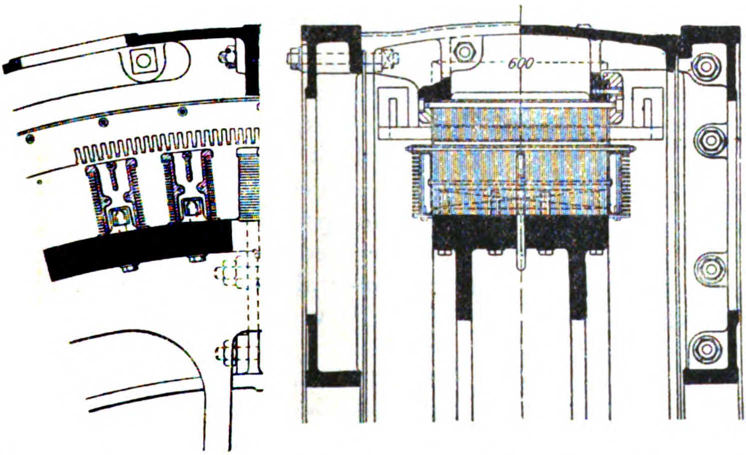


FIG. 29.—Three-phase Alternator by Siemens and Halske. Output 2,000 k.w., 2,200 volts, 50 cycles, 83·5 revolutions, 72 poles. Diameter over Poles 235 inches, giving Peripheral Speed of 5,150 feet per minute. Air-gap 0·47 inch. Diameter of Shaft 19·8 inches.

The objection to the Steinmetz formula is that it can only be used within limits, as it takes no account of speed. For this reason the better known "*output equation*" below is to be preferred. In this the output in watts is equal to a coefficient multiplied by the number of revolutions per minute, by the diameter squared, and by the length in inches.

$$(\text{Watts} = \text{coefficient} \times n \times d^2 \times l.)$$

The figure in this case is a decimal quantity, and from data taken of many machines the writer finds that it varies somewhat as follows:—

	Coefficient for output equation.
For the largest flywheel generators	·033
„ large multipolar dynamos	·03
„ medium size multipolar dynamos, say about 300 K.W. ...	·025
„ small multipolar dynamos	·018

To continue for bipolar dynamos the values are :—

For large bipolar dynamos	·014
„ medium size bipolar dynamos, say about 30 K.W. ...	·01
„ small bipolar dynamos	·007

With the help of this formula, given the output of a machine and its speed, we can find d^2l, and having found the "*size constant*" of the machine, it is then only necessary to divide the two factors in such a way that it meets proportions which are known from experience to be best for any given carcase. For example, it is known that for high values of d^2l the armature becomes more and more "*fly-wheelly*," to use one of Dr. Thompson's expressions. With this in view the writer has prepared Table IV., giving proportions for various values of d^2l; also the number of poles and approximate weights of the various essential parts of the machines.[1]

With regard to the detailed dimensions of the machines, the writer has found that these may be roughly taken as a percentage of the diameter as indicated in Figs. 21, 22, and 23, the results given in the figures being averaged from a number of examples. Although at first sight the method may seem crude, the writer has found a wonderful agreement between many varying designs. In the case of bipolar machines the whole of the dimensions may be given as a percentage of the diameter of armature, but in the case of multipolar dynamos the pole dimension measured circumferentially is arrived at by multiplying the number of poles by four and then allowing three of the parts for a pole and one part for the space between the pole tips (see Figs. 21 and 22). Calling the dimension measured across the face of the pole between the pole tips B, the dimension across the pole inside the magnet coil should be ·75 B. Of course these percentages are only intended to be approximate.

[1] As a comparison Table V. has been prepared on the same lines for bipolar machines.

Where the result is a decimal, then the nearest even figure should be taken. The final dimensions would, of course,

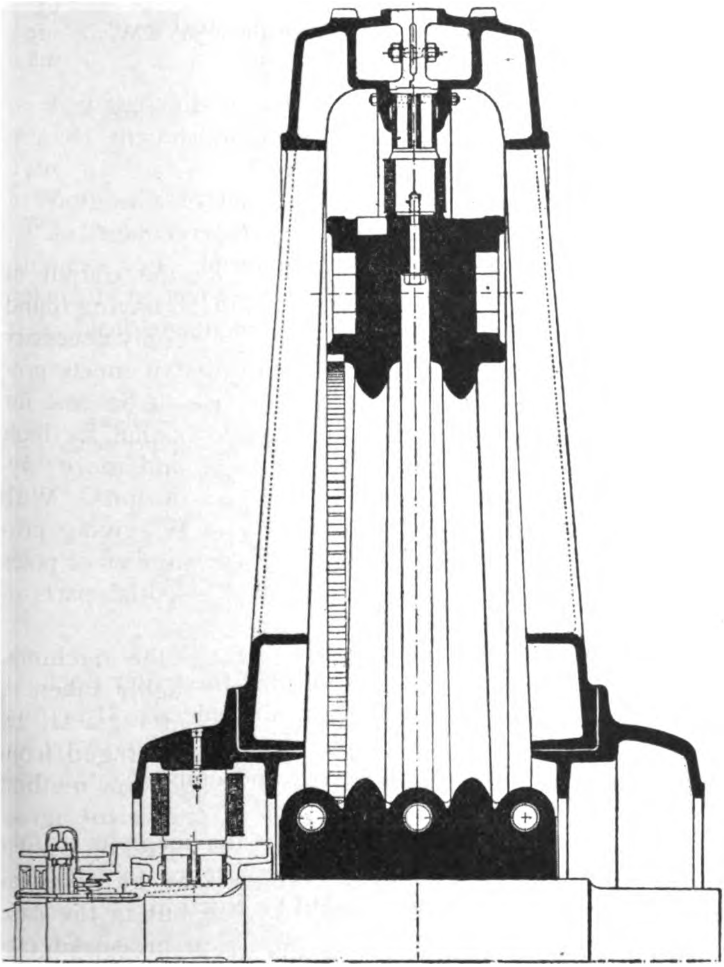


FIG. 30.—Three-phase Alternator by the Compagnie Internationale d'Electricité, Liège (I.E.E. Co., London). Output 1,000 k.w., 2,200 volts, 50 cycles, 83 revolutions. Diameter 216 inches, giving a Peripheral Speed of 4,720 feet per minute. Air-gap 0·335 inch. Diameter of Shaft 23·7 inches.

be fixed after the electrical calculations have been checked over.

Fig. 24 gives curves of actual cost of material and labour for a series of multipolar machines, and it is interesting to

note that when plotted in this way, that is, with the horizontal line in values of d^2l, we get practically a straight line. The writer has found the equation to the "*total cost*" line for a certain series of English machines to be

$$x = 140 + \cdot 018 \times d^2l.$$

Of course the curves would vary with different makers, and also according to whether the establishment charges were arrived at in the way indicated.

An interesting study for any given set of conditions in a given shop is the analysis of the cost percentages of the various items which go towards material. For example, taking a machine with an armature say 5 feet in diameter, the writer has found the following percentages hold fairly well :—

Materials—	Percentage of total cost of material.
Armature copper	6 per cent.
Field copper	19 "
Commutator copper	6 "
Armature stampings	12 "
Field poles	7 "
Yoke	20 "
Insulating materials	8 "
Miscellaneous	22 "

Of course it must be understood that the writer does not put these particulars forward as at all general. It is quite impossible to compare various workshops in this way, but any one shop can plot such curves and employ such percentages with advantage.

A rule which gives a direct clue to the diameter is that the current density per inch of circumference, or the "*circumferential-current density*," should be equal to

$$\frac{\text{the number of conductors} \times \text{the current in one conductor}}{\pi \times \text{diameter of armature in inches}}$$

If the result given by the formula is above 700, it indicates a skimped design, except in the very largest machines; and on the other hand, if it is below 300, the dimensions of the machine may be taken as being too liberal. Results of various machines by this rule are given in the last column but one in Table III. For the ordinary run of multipolar machines about 500 is a good average.

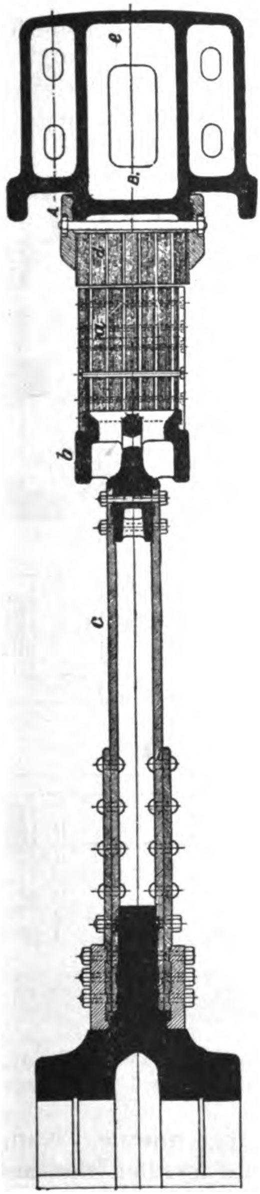


FIG. 31.—Three-phase Westinghouse Alternator for the Manhattan Elevated Railway. Output 5,000 k.w., 11,000 volts, 25 cycles, 75 revolutions, 40 poles. Diameter over Pole-tips 384 inches.

Of course in comparing the outputs of machines a great deal depends on the peripheral speed, and this varies between exceedingly wide limits. For example, the Siemens dynamo at top of Table II. runs at 5,320 feet per minute, whereas the average speed of the machines given in Tables II. and III.

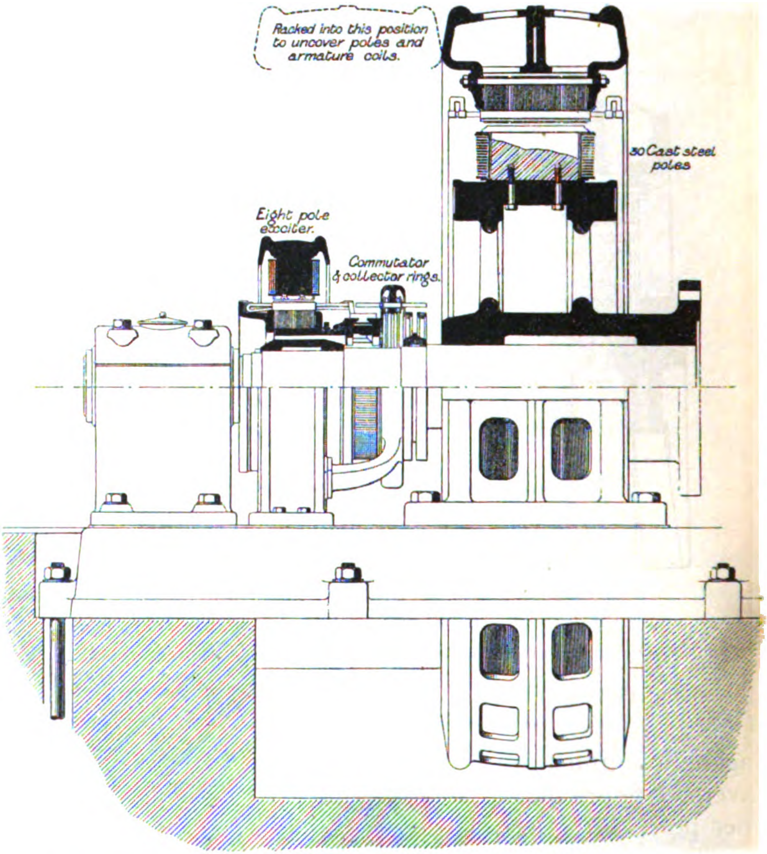


FIG. 32.—Design for a 1,400 k.w. Two-phase Alternator, 50 periods, to run at the high speed of 200 revolutions.

is under 3,000 feet per minute. Naturally the higher the peripheral speed the greater the output which can be obtained from a given sized carcase.

The Siemens machine above mentioned is curious in another respect, in that the peripheral speed of the commutator is as high rate as 3,420 feet per minute. There are

only three cases in Table II. and four in Table III. where the peripheral speed exceeds the limit which has come to be regarded as general practice, namely, 2,500 feet per minute. The question of resisting centrifugal action calls for an even lower velocity on the commutator.

The number of poles is really fixed by the amount of current which can be collected at any one pole, and this

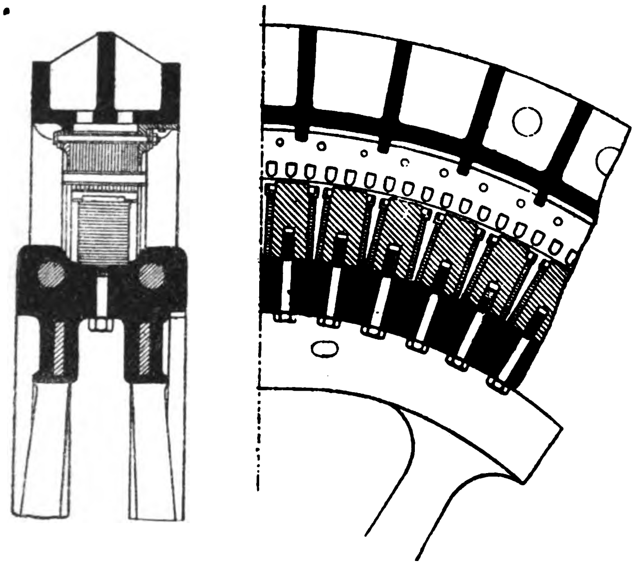


FIG. 33.—Alternator by A Grammont. Output 860 k.w., 2,400 volts, 50 cycles, 94 revolutions, 64 poles. Diameter over Poles 196 inches, giving Peripheral Speed 4,820 feet per minute. Air-gap 0·275 inch.

again is limited by the line density in the air-gap. An average figure may, however, be taken at 500 amperes per pole.

The standard practice in induction densities in the various parts of the magnetic current may be taken as follows :—

	Per sq. cm.	Per sq. inch.
Armature core	9,000 to 12,000 ...	58,000 to 78,000
„ teeth	17,000 to 19,000 ...	110,000 to 123,000
Air-gap	7,000 to 9,000 ...	45,000 to 58,000
Cast-steel poles	13,000 to 15,000 ...	84,000 to 97,000
Cast-steel yoke	9,000 to 12,000 ...	58,000 to 78,000
Cast-iron yoke	5,000 to 6,000 ...	32,500 to 39,000

Designers appear to be practically agreed that to get sparkless commutation and a minimum zone of movement of the brushes, there must be a certain relationship between the ampere turns required for the air-gap at full load, and the cross ampere turns of the armature. Some say that the best relationship is when the one divided by the other gives unity or thereabouts. At the same time, many machines, especially those made in America for traction purposes, show figures which according to this rule would indicate a precarious design. Thus, if we take the four dynamos which are given in Messrs. Parshall and Hobart's book on Electric Generators, we get the following figures:—

Kilowatts	1,500	200	300	250
Amperes	2,500	400	2,400	455
Volts	550/600	500/550	110/125	500/550
Revs. per minute ...	75	135	100	320
Number of poles ...	12	6	10	6
Gap ampere turns at full load per pole...	6,000	4,800	4,900	4,150
Cross or distorting ampere turns at full load per pole ...	9,500	7,900	7,200	6,380
$\dfrac{\textit{Gap ampere turns}}{\textit{Cross ampere turns}}$	·631	·61	·68	·65
Current collected per pole	416	134	500	150

It is obvious that if good commutation can be obtained with this constant

$$\frac{\text{Gap ampere turns}}{\text{Cross ampere turns}}$$

much lower than unity, then such a machine will be a cheap one, because a large number of cross ampere turns means that a larger output is obtained from a given carcase.

The following conditions tend to this result:—

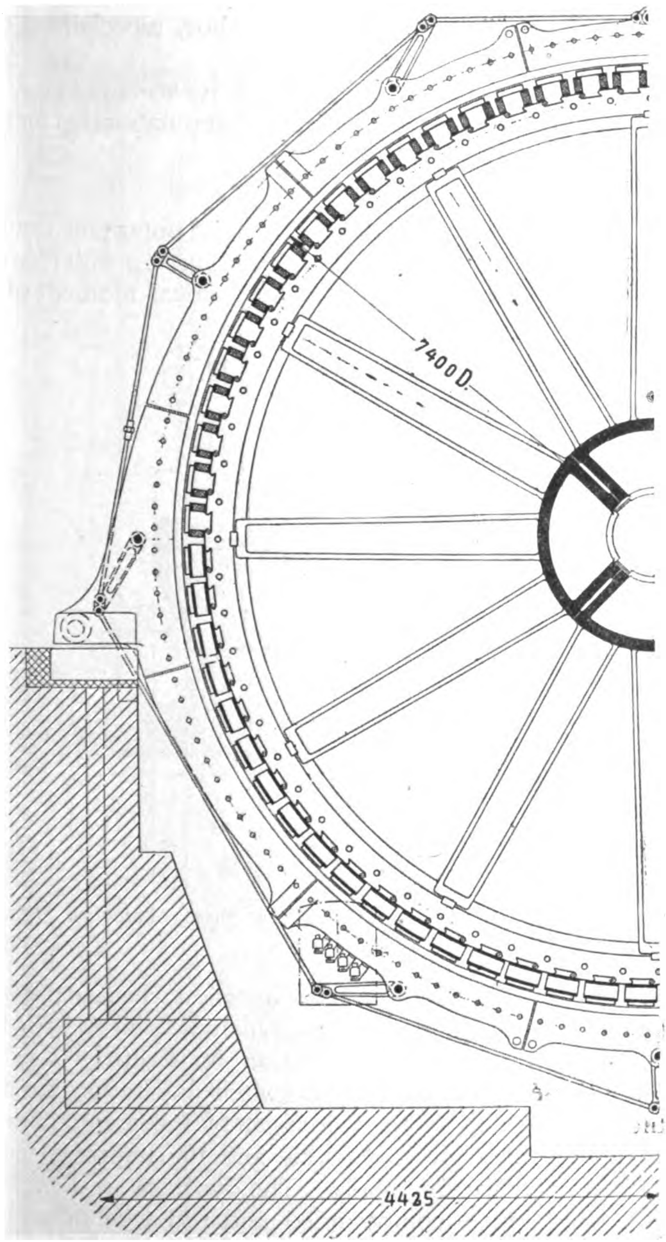


FIG. 34.—5,000 k.w A.E.G. Three-phase Alternator, showing Tie-rod Construction.

(*a*) The use of carbon brushes.
(*b*) The saturation of the pole shoe, especially at the pole tips.
(*c*) The saturation of the teeth of the armature core.
(*d*) The use of high-resistance commutator lugs for the segments.
(*e*) The fields being over-compounded.

The writer considers the last a most important feature, because the *increase of magnetisation* occurring with increase of load comes into action just at the critical moment when

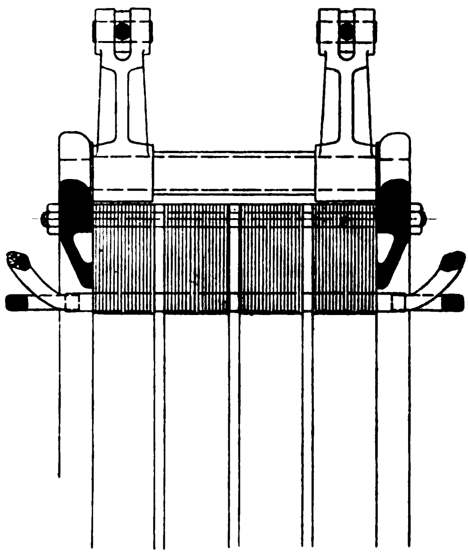


FIG. 35.—Detail of 5,000 k.w. A.E.G. Three-phase Alternator. Brackets for Tie-rods.

it is required. In fact, it is just a question whether it would not be as well to compound *all* dynamos, simply with this object in view. In a central station for lighting it would mean a little extra cable and switch apparatus, but this would be much more than covered by the greater output obtainable from a given machine and the improved commutation under varying loads. The dynamos in a traction station are always compounded and run well in parallel without trouble, so the writer cannot see why dynamos for lighting should not be compounded also. It is clear that as the motor load grows in any particular area the conditions

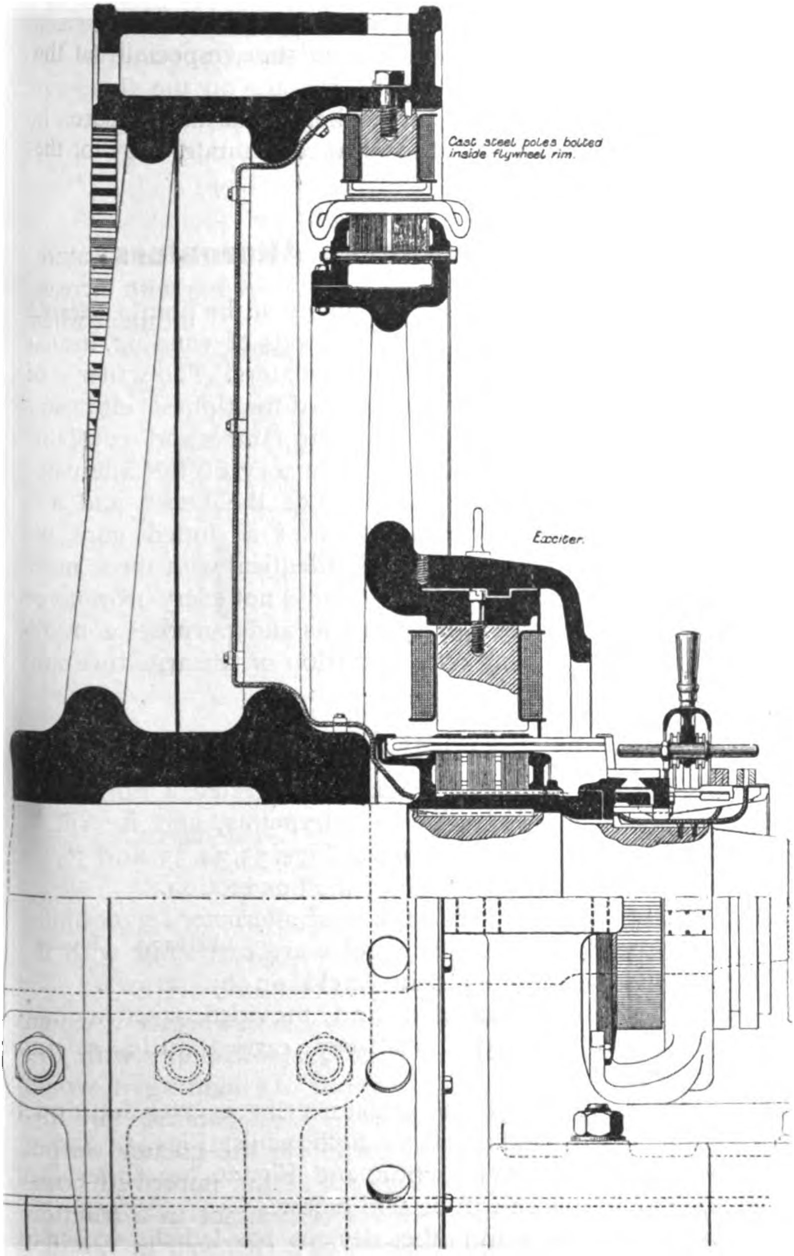


FIG. 6.—Outer-pole Type of Three-phase Alternator for supplying power at the British Xylonite Works.

which the dynamos have to meet approximate more and more to those of a traction generator. Of course the fact that practically all lighting networks are on the three-wire system, and that batteries are generally used are points in favour of keeping to shunt machines.

Part II.—Multiphase Alternators.

It will be evident that a good many of the points referred to above as to armature iron, methods of winding, insulation, etc., are also applicable to alternators. The writer is of course considering only the standard multiphase alternator having a stationary slotted core armature and revolving poles with a coil on each. The history of the alternator has been a case of the survival of the fittest, and it is significant that, with the addition of a slotted core, the alternator of to-day is practically identical with those made by the old Elwell Parker Co. For is not every iron-cored single-phase alternator to all intents and purposes a multiphase machine having only a portion of the armature slots utilised ?

Typical Designs.

In Figs. 25 to 36 the writer has collected a number of typical designs of multiphase alternators, and it will be noticed that with the exceptions of Figs. 33, 34, 35, and 36, the armature ring castings are all of the box section.

Fig. 25 shows a typical design of alternator for coupling to high-speed engines. The poles are cast solid with the wheel, the pole shoes being held on by screws. The magnet wheel is extended and provided with a half-coupling, so that the shaft-key carries little or no twisting stress.

In Figs. 29 and 30 the armature ring is extended down each side to give additional strength, whilst Figs. 34 and 35 show the *Tie-Rod* construction, and Fig. 36 the *Outer Pole* type, of which more will be said below.

A study of these and other designs has led the writer to draft the following specification of a modern multiphase alternator :—

Type.—Three-phase in preference to two-phase, as being

more generally convenient and giving a greater output from a given-sized carcase.

Connections.—Star connection in preference to mesh, this being the usual method of connecting motors and lamps. The stress on the insulation is also less than two-thirds what it would be with mesh connection, whilst with the mesh connection any deviation of E.M.F. from a sine curve may set up internal currents.

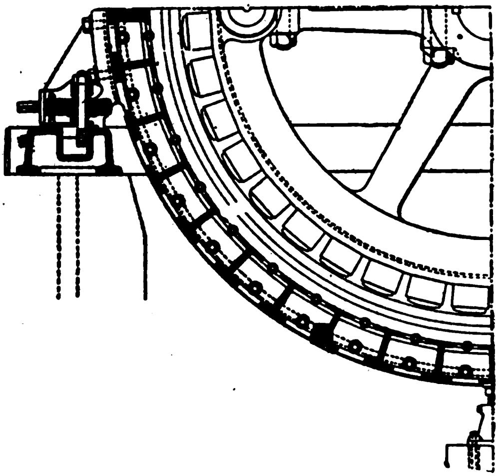


FIG. 37.—Adjustable Foot Bracket to support Armature Ring of Ganz Alternator.

Number of slots.—Two slots per pole per phase. One slot is cheaper to wind, but with two slots the curve approximates more closely to a sine curve. Three slots are too expensive.

Shape of slot.—Half-open tunnel or parallel slot in preference to tunnel, because former-wound coils can then be employed. Tunnels require the coils wound in place, and there is liability of armature leakage across the strip of metal at top.

Poles.—Magnet cast steel of ample area, so that magnetic line density, and therefore the exciting current, can be kept as low as possible. A coil on every pole.

Shape of pole.—Round if possible, but at any rate oval, so as to reduce the leakage from pole to pole and

enable the winding to be edgewise bare copper strip.

Pole-pieces.—Laminated, with the pole-tips cut back and reduced in area so as to give approximation to sine curve and reduce armature leakage to a minimum.

Damping-coils.—Copper castings between the pole-tips and connected up at end. Amortisseur coils necessitate holes in the pole-pieces, and are therefore more expensive to arrange.

FLYWHEEL.

The continuous-current dynamo has usually a flywheel keyed alongside it to help the even-turning movement, but in the case of the alternator there is no separate flywheel. Alternator construction has therefore become closely bound up with the flywheel, and the design of the latter is arranged accordingly. For example, the wheel is generally provided with double arms, not for extra strength but to provide space for the pole bolts.

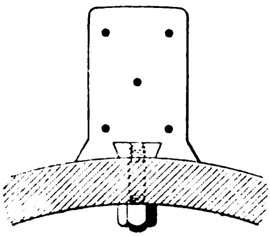


FIG. 38.

The most usual method of fixing an alternator flywheel to the shaft is to cast the boss in sections and have two very heavy shrink rings round the boss. If properly done no key is required. The rim of course must be continuous, as the poles are necessarily pitched very close together. One of the best methods of fastening the two halves of the flywheel is by the link and lug joint, and if the rim is of good depth the shrinking links may be circular and therefore easily and accurately fitted.

In some very large 5,000 k.w. three-phase Westinghouse alternators for the Manhattan Elevated Railway arms are dispensed with altogether, the rim and the boss being secured together by two webs of riveted rolled-steel plates, see Fig. 31.[1]

[1] It is interesting to note that the flywheel rim of the Korting alternators is made extra wide so as to cover the Dettmar electro-magnetic brake which forms part of the bottom half of the armature ring. This electric magnet forms a very convenient method of applying an artificial load for synchronising or testing.

Adjustment of Air-gap.

The accurate adjustment of air-gap is one of the problems of alternator construction, because the diameters of alternator armatures (15 or 20 feet) are great as compared with the usual air-gap, of say $\frac{5}{16}$ inch. An expensive armature construction may really be the means of cheapening the machine as a whole, by enabling a short air-gap to be employed, because it means less field copper, less leakage, and therefore a lower voltage drop.

A common method of adjusting the gap is by means of screw wedges under the feet and at the bottom of the armature ring. In some cases the feet of the armature ring are cast separately, and provided with both vertical and horizontal adjusting screws as in Fig. 37.

In the Siemens and Halske machine the air-gap is adjusted by a special fitting provided with adjustable rollers on which the bottom of the armature ring is supported. The rollers can be raised or lowered separately or together; if adjusted together they give a vertical displacement, whereas if one only is moved the displacement is horizontal.

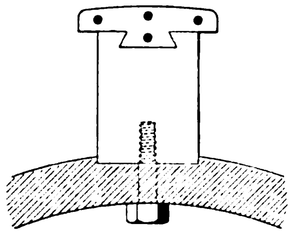


Fig. 39.—Laminated Tips cast into Steel Pole.

One way of approximating to an equality of air-gap is by what may be called the "Brown" construction, shown in Fig. 30. The armature ring has arms down each side, which rest on trunions, and the periphery of the armature ring is fitted with a rack so that it may be barred round and the coils of the bottom half, examined and cleaned.[1] At Frankfort, where this type of machine is employed, the motor for barring the flywheel is also used for barring round the armature ring.

Tie-rod Construction.

When the Schuckert machine, having radial tie-rods to

[1] The only way to clean a dynamo machine effectually, whether it is an alternator or a dynamo, is by means of an air-blast. For high-voltage machines the air-blast is especially necessary, as a damp cobweb between the coils may be dangerous. Where a station is fitted with air-blast static transformers a pipe can be connected temporarily to the air chamber, or where such transformers are not used a small centrifugal fan can be belted up to the alternator shaft.

give stiffness to the frame, was shown at the Paris Exhibition, it came in for a good deal of adverse criticism. The light built-up armature ring, instead of a massive casting, was a distinct innovation, but when one considers that the problem is very similar to that of bridge construction, the wonder is that the built-up framing was not tried at an earlier date.

In alternators of comparatively small diameter it is easy to give such a section to the armature ring that there is practically no deformation when set up in position. As the diameter increases, however, it becomes more difficult to ensure that the alternator ring shall keep to an exact circle when erected vertically, more especially as castings of very large diameter are usually bored out, machined, and wound whilst in the horizontal position.

When a round body of large diameter is brought from an horizontal to a vertical position, any change in form by the action of its own weight is likely to be still further increased by the magnetic pull of the poles. Of course, in the case of alternators driven by vertical spindle turbines, this difficulty does not arise; in fact, a vertical spindle is ideal, as it admits of the umbrella type machine and so does away with all armature deformation. When one comes to think of it there is really no reason why an engine crankshaft should not be arranged vertically; it works extremely well for dock pumping, and much of the weight on the footstep could be relieved by placing the armature out of centre and so giving a magnetic pull upwards, or possibly a special electro-magnetic device could be fitted for the purpose. The A.E.G. design for the construction is shown in Figs. 34 and 35, and it will be noticed that the tie-rods (with right- and left-hand screws) are arranged tangentially with the armature core. When the machine warms up, these rods tighten, and the whole machine is rigid. Such a construction reduces the weight, and therefore the expense of material, carriage, etc. The armature simply consists of core plates (open to the atmosphere on the outer periphery) clamped between standard cast-iron end rings as in the earliest Elwell Parker alternators.

Inner Pole Machine.

The Outer Pole or Niagara[1] type of machine shown in Fig. 36 has the advantage that the flywheel rim can be made practically of any weight, and it is thus very suitable for driving by single-crank, slow-running engines, especially the large gas-engines which are now coming so much to the front. The armature casting is a hub and therefore not liable to deformation, and as the poles are inside the fly-wheel rim, the pole-bolts are relieved of all stress due to centrifugal force. The armature is also cheaper to construct because less iron and copper are required.

A feature of the International Electrical Engineering Co's. design in Fig. 36 is that the exciter forms part of the armature support, thus economising space and enabling current to be taken off the commutator at one end of the brush spindle, and passed into the collector rings at the other. This does away with all loose connecting cables.

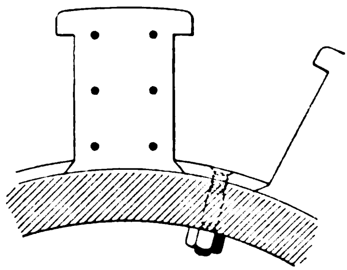


Fig. 40.—Oerlikon Method of holding Laminated Pole.

Fig. 32 shows this idea applied to the exciter of a high-speed machine which has its armature fitted with a racking device to uncover the coils. The exciter very conveniently occupies the extra piece of shaft which is usually wasted.

Poles.

Where the racking device is not provided the poles must be capable of being withdrawn endways so that they may be removed for examination of the armature, and they are sometimes held by vee grooves, as shown in Fig. 38, so as to be easily removable.

Just as in continuous-current machines it was pointed out that an increased line density around the air-gap was a desirable feature, so in an alternator the same holds good.

[1] It is interesting to note that this design—first introduced, by the way, at Cairo by Mr. C. E. L. Brown—has been discontinued in favour of the inner pole type for the latest machines installed in the Niagara station.

Independently of the question of eddy currents therefore, laminated pole-pieces are good practice. The solid pole with laminated tip, as Fig. 39, is better than a pole laminated throughout, because it gives a smaller cross-section and shorter mean turn for field magnet copper, also less leakage between the poles.

When the pole-tips only are laminated they are usually cast into the pole, as shown in Fig. 39, or they may be loose and held on by double-headed keys. When the pole is entirely laminated, it is fastened to the flywheel by means of a square bar passing right through the plates, as shown in Figs. 26, 28 and 29. Fig. 40 shows the method employed for attaching the poles on the Oerlikon type alternators at the Fulham Central Station, and Fig. 41 shows the A.E.G. method of using cotters.

The Ferranti edgewise winding is so entirely superior to any other method for alternators that its use is practically universal. The winding can be made to have no spring by rolling the strip on its outer edge, so that on leaving the rolls it curls up straight away to the radius desired. Of course this rolling method can only be used when the poles are circular. If they are oval in shape (which is most usual) the copper strip must be wound or drawn on to a former to get it to the required shape. The coils rotate at a very high speed and they must be pressed up tight, turn to turn, when placed in position.

In the latest 5,000 H.P. generators at Niagara there are four layers of edgewise strip winding to each field coil (rectangular poles), a clear space being left between the layers for ventilation.

Armature.

The depth of the armature core is more often than not made greater than it need be, purely for mechanical reasons. At high periodicities—that is, 50 and over—the dimension of the pole measured circumferentially is relatively small, and this, of course, only calls for a shallow armature core. To give mechanical strength, however, the core is usually made deep enough for poles giving 25 periods, and at that particular diameter of machine, is so fixed, whatever the periodicity. It is good practice to shorten the magnetic

circuit as much as possible, and for this reason the poles must not be too long nor the armature slots too deep.

Some armatures are bored out after they are built, and on this account the tunnels are *not* cut through, but are punched close up to the inner periphery of the core, so that after being machined the strip of metal at the top of the slot is very thin. With slots or half-open tunnels the armature can be bored out by filling temporarily with wood, but the best method of machining the interior surface is to employ a grinding wheel, which runs backwards and forwards, the armature being moved slightly after each journey. This method has the very great advantage that it does not burr the plates over, and it gives extremely accurate results. Where an armature has tunnels the web at the top of the tunnel should be sawn through, for in boring, the plates get badly burred, and to reduce eddies it is necessary to split up the surface.

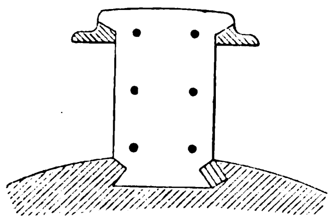


FIG. 41.—A.E.G. Method of holding Laminated Pole.

In order to reduce the liability to leakage which must occur when the line density in teeth is pushed to a very high degree, the E. C. Co. punch out vee-shaped slots at the root of each tooth, as shown in Fig. 42 (similar to the Bergmann dynamo). The point of greatest line density is thus transferred to the root of the tooth, where leakage cannot occur to any extent. Further, whilst not interfering very much with direct magnetisation, the notches add somewhat to the reluctance in the cross-magnetisation path, which is, of course, a good feature.

MACHINING SLOTS.

To mill out all the slots of an alternator core, some sixteen feet or so in diameter from the solid, appears at first to be somewhat of an undertaking, yet it is often done, *e.g.*, the 1,600-k.w. 10,000-volt Lahmeyer machines for the Charing Cross and Strand Co. have each some 500 slots about $\frac{3}{8}$ inch × $1\frac{1}{2}$ inch, milled from the solid. Three Collett and Engelhärt machines worked on each ring.

There is no doubt that a milled-out slot enables the insulation of the armature coils to be effected in a most thorough manner, and if the core is first dried, the burring of the plates is not serious. Even when the holes are punched out beforehand they generally have to be cleaned out with a milling cutter if they are parallel slots. A drift or file must be used when tunnels are employed, and Fig. 43 shows Mann's slot-cleaning machine, which has been specially constructed for rhymering out such tunnels.

Cyclic Irregularity.

The question of cyclic irregularity depends mainly on the type of engine. Of course the ideal condition, is the even turning given by a turbine, and from this point of view the more cranks there are on an engine the better. A good deal, however, depends on how the cranks are arranged, and also on the character of the governing. A single crank engine is better than the usual two-crank type at right angles, because there are fewer points of minimum and maximum speed per revolution. In this country the three-crank engine with the alternator coupled on an extension shaft at one end has been extensively adopted, whilst on the Continent very excellent results have been obtained with single-crank tandem compound engines. At Frankfort, for example, there are a number of such units; they all run at the same speed, the cranks being first brought into synchronism by electric bell contacts on the flywheels.

The large 5,000 k.w. machines for the Manhattan Elevated Railway are driven by combined horizontal and vertical steam engines, so as to equalise the turning movement as much as possible.

A great deal can be done to help cyclic regularity by fitting the poles with damping coils. With poles of solid steel it is generally sufficient to make the flange of the magnet coil nearest the pole face of very heavy section gunmetal or copper. In fact, these are often arranged to span from pole tip to pole tip. If the poles are laminated, Leblanc's amortisseur coils, consisting of several solid copper rods let into the face of the pole and short-circuited at the ends, are generally employed. The effect of this low-resistance circuit round the poles or the amortisseur coils is to retard any

shifting of field magnetism across the pole face and so tend to correct variation in angular velocity.[1]

Voltage Drop.

It is important that the voltage drop should be as small as possible, for besides making electric lighting more difficult a large drop is detrimental to the efficient running of induction motors, inasmuch as the torque of such motor varies with the square of the impressed voltage.

The voltage drop of a multiphase alternator is due to ohmic resistance of the copper eddy-currents, armature reaction, armature leakage, and increase of field-magnet leakage from no load to full load.

The eddy-currents set up on the face of an alternator-pole have the effect of demagnetising, and they thus, to a slight degree, increase the drop, and from this point of view a laminated pole-piece is best.

At present the drop is the principal limiting factor of output, being generally about three to eight per cent. with power factor unity, and ten to twenty per cent. with power factor 0·8. Obviously if some good method of compounding could be introduced the designer need not worry about the amount of drop, as he would know that this could be corrected by the compounding, as in the case of an ordinary continuous-current dynamo. This would also result in the output of any given carcase being considerably increased.

Magnetic leakage is the most important factor in alternator design. Of two machines, both of which give the same "*size constant*" d^2l, that which has the largest diameter will, other things being equal, give the best results, because with a given number of poles they are further apart, and, therefore, there is less leakage. On the other hand the expense is greater. Where the periodicity is high the large

[1] The armature current sets up magnetic poles over the core surface, and any change in the relative position of these armature poles and the field poles causes the damping coils to be cut by the shifting armature magnetism, and currents result which oppose this shifting of magnetism. The solid copper rods in the polar surface act as a squirrel-cage winding, and in case of the alternator losing its exciting current the machine will continue to rotate as an asynchronous motor. There is therefore much less liability of breakdown. Gun-metal castings between the poles and partly covering the horns are efficient for damping, but not sufficient to cause the machine to run as a motor.

number of poles required may bring them within a few inches of each other, and there is considerable leakage, even when the air-gap is reduced below the mechanically safe limit. Low periodicities are therefore preferable from the manufacturing point of view.

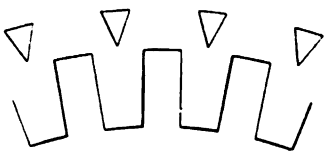


FIG. 42.

If there is a bridge of metal at the top of the tunnel it soon gets saturated to its utmost limit, and acts practically as an air-gap. At the same time it must be remembered that it is only when the poles are in a certain position that saturation occurs. The lag of the armature current causes it to act on some of the bridges when they are removed from the direct influence of the poles, and, therefore, not saturated. On this account it is best to have half-open tunnels.

We have seen that in dynamos, armature-reaction may be reduced by working at high-line densities[1] on the magnetic material near the air-gap, and by placing reluctance on the cross-field, just in the same way the behaviour of an alternator can be improved by keeping these points in view. The drop, particularly at full load, may be kept down by so designing the machine that there is only a small *difference in the leakage at full load and no load.* The actual amount of leakage is not so material, although, of course, it should be as low as possible, but what is important is that the *difference* should be small.

SHAPE OF CURVE.

There is a commercial limit to which the number of tunnels per pole per phase should be pushed, but obviously the more distributed the winding the better the use which is made of the armature-iron. The more even the line-density and the more nearly does the curve approximate to a sine curve.

The apparent refinement of getting as near to a sine curve as possible repays for any extra trouble, in that it reduces the stresses on the insulation and, to a certain

[1] It may be well to note that as the speed of an alternator is governed directly by the periodicity, it is necessary to have something in hand when fixing on the line-density in the teeth, otherwise the required voltage may not be obtained.

extent, gives a saving of energy. The self-inductance of a circuit smooths out irregularities in the potential curve to a certain extent, but, at the same time, where rotary converters are employed, it is well to take extra precautions to get as near a sine curve as possible.

Good results are obtained by bevelling the tips of the field-poles, so giving a better distribution of magnetic lines.

Tables, etc.—Multiphase Alternators.

Alternators are usually worked at higher peripheral speeds than dynamos, for one thing because the periodicity requires a larger number of poles, and to find room for them large diameters are necessary. As will be seen from Table VI., speeds of over 5,000 feet per minute are common. As a matter of fact well-made shrink-ring jointed cast-steel flywheels may be run at 7,000 feet per minute and still have a fair factor of safety. Cast iron is limited to about 5,000 feet per minute. The weight of a flywheel alternator being relatively so very great, it is only possible to keep the shaft within reasonable dimensions by reducing the distance between the bearings, for the deflection of a shaft is roughly proportional to the cube of the distance between the bearings. On this account the necessary weight is usually obtained by making the magnet wheel serve as the flywheel, and velocity squared is obtained by increasing the diameter to its utmost limit. With a built-up construction as shown in Fig. 31, a peripheral speed of as high as 8,000 feet per minute can be attained.

Table VII., which is deduced from Table VI., gives coefficients as in the case of the multipolar dynamos, and it will be seen that they vary considerably, *e.g.*, applying the Steinmetz formula to alternators the figure appears to vary from two to eight, and in the "*output equation*"

$$\text{Watts} = \text{coefficient} \times n \times d^2 \times l,$$

the figure varies in somewhat the following manner :—

	Coefficient for output equation.
For the largest flywheel alternators	·03
„ large alternators	·02
„ medium size alternators, say 300 k.w. ...	·01
„ small alternators	·005

Table VIII. gives the proportions of a line of two-phase alternators for various values of d^2l. It will be noticed that as the machines get larger in diameter, the length of the core tends to remain at about 10 per cent. of the diameter. As a matter of fact, in getting out a new machine many designers arrange the size so as to get a circular section-pole. The particulars given in Table VIII. are for two-phase machines on a non-inductive load.

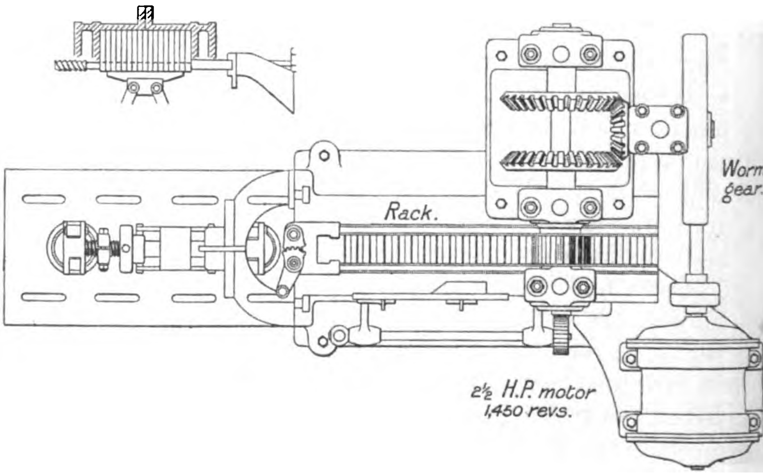


Fig. 43.—Mann's Slot-clearing Machine.

The percentages of the various items which go to make up the material for a machine say 7 feet diameter, are given below—

Materials—	Percentages of total cost of material.
Armature copper	2 per cent.
Field copper	9 ,, ,,
Armature stampings	13 ,, ,,
Field poles	8 ,, ,,
Insulating materials	5 ,, ,,
Armature shell, flywheel, shaft, bearings ...	42 ,, ,,
Miscellaneous...	21 ,, ,,

I have to thank the various firms, including Madame Dunod and Co., the publisher of *l'Électricité a l'Exposition de* 1900, who have kindly supplied several of the drawings illustrating this paper.

TABLE I.—PARTICULARS OF V

MAKER.	OUTPUT. K.W.	OUTPUT. Amps.	OUTPUT. Volts.	OUTPUT. Revs.	TYPE. Winding Armature and Field.	ARMATURE. No. of Poles.	ARMATURE. Extreme Diameter of Armature Core.	ARMATURE. Length of Armature Core.	ARMATURE. No. of Slots.	ARMATURE. Sectional Area of Core.	ARMATURE. Total number of Conductors.	ARMATURE. Sectional Area of each Winding.	ARMATURE. Diameter of Shaft.
							c.m.	c.m.		sq. c.m.		sq. m.m.	c.m.
Siemens Bros. & Co.	1,530	2,780	550	200	Drum Shunt	16	274	58·5	308	2500	1,232	132	35·6
Siemens & Halske	1,000	1,850 2,000	550 500	95	Drum Shunt	14	250	54	286	600	1,144	72	60
International Electrical Engineering Co....	800	3,080	260	58	Drum Shunt	18	300	37	360	520	1,440	58	50
Société Alsacienne de Constr. Mecaniques *	750	1,500	480/600	70	Gramme Shunt	12	381	50		710	2,496	60	40
Schuckert & Co. ...	750	1,500	500	83⅓	Drum Shunt	14	253	40			1,072		
General Electric Co. of Creil ...	700	2,800	250	120	Drum Shunt	14	225	51		505	812	76	60
Societa Esercizeo Bacini de Genes	500	1,000	500	160	Drum Shunt	16	290	35	516	740			25
Decauville Co. † ...	400	1,600	250	75	Drum Shunt	10	285	35		520	1,250	45	57
Postal-Vinay ...	350	600	580 600	90	Drum Comp'd	8	160	60	408		832		45
Mather & Platt ...	350	1,400	230 250	105	Drum Shunt	12	210	47	264	800	1,050	50	33
Lahmeyer & Co....	350	635	550	94	Drum Shunt	12	240	42	600	950	1,218	36	32
Ernest Scott & Mountain	330	1,440	230	90	Drum Shunt	8	150	50	184	900	736	70	46
Maubeuge Blast Furnace Co ...	280	1,120	250	120	Drum Shunt	12	235	50	288			65	44
Alioth	225	450	500	280	Drum Shunt	10	150	35		325			20
Société L'Eclairage Electrique	200	850	235	110	Drum Shunt	12	200	35		240			32

* The gramme ring revolves outside the poles, an

† Magnet coils wound on yoke between each pair

…rious Multipolar Dynamos.

Field Magnets.					Commutator.				Weights.				Efficiencies.		
Length of Magnet Coil.	Polar Surface.	Air Gap.	Poles, Laminated or Solid.	Section of Wire.	Diameter.	Useful Length.	No. of Segments.	Number of Carbon Brushes.	Armature Copper.	Field Copper.	Commr. Copper.	Armature Core Iron.	Full.	¾	½
c.m.	sq. c.m.	m.m.		sq. m.m	c.m.	c.m.			k.g.	k.g.	kg.	kg.	per cent.	per cent.	per cent.
[illegible]	2,100	15·9	Solid	19·7	167·5	55	616	16 Sets of 19 each	2,000	3,215	1,670	8,250	94¼	93¾	91¾
[illegible]	2,000	9·11	Lamina'd	19·6	210	30	572	14 Sets of 10 each	1,000	3,700	1,100	5,300	94	92	90
[illegible]	1,330	10	Solid	34	240		720	18 Sets of 8 each	1,150	2,844	1,035	4,000	94	93	91
[illegible]	3,000	40	Solid	21	381	50	2,496	Copper 12 sets of 4 each	3,200	4,500		6,000	94·7	94	92·4
[illegible]	2,000	2·9	Solid		170	20	536	14 Sets of 3 each	1,030	3,250	900	5,200	93·5		91·6
[illegible]	2,400	18	Solid	24·63	160	18·5	406	14 Sets of 4 each	800	2,940	550	3,250	94	92	90
[illegible]	1,050		Solid	9·5	100	11·6	516	16 Sets of 2 each							
[illegible]	1,800		Solid	22	200	26	625	10 Sets							
[illegible]	330	10	Solid		120	25	416	8 Sets of 4 each					93·2		
[illegible]	1,700	7	Solid	16·4	180	30	528	12 Sets of 5 each	590	1,500	1,180	2,350	93	92	90
[illegible]	1,640	7	Solid	7·5	200	16	600	12 Sets of 3 each	500	1,300	380	4,500	93	93	92
[illegible]	2,450	11	Solid	23	100	25·4	368	8 Sets of 5 each	690	3,000	970	2,770	92	91	90
[illegible]			Solid	12·5	180	20	288	12 Sets of 6 each							
[illegible]	1,220	8	Solid		88	10		10 Sets of 5 each	250	550	350	1,200	92	93	89
[illegible]	1,230		Solid		120	20	276	12 Sets of 4 each							

…ors on outer periphery form the commutator.

TABLE II.

Coefficients, etc., Deduced from Table I.

Maker.	K.W.	Revs. per Min.	Dia. over Armature.	Length of Armature Core.	Diameter Squared in Ins. Multiplied by Length in Inches.	Peripheral Speed. Feet per Minute.		Coefficient by Steinmetz Formula :— $\frac{\text{Dia.}'' \times \text{Length}''}{\text{K.W.}} =$	Coefficient from Formula :— Watts $= k \times n \times l \times d^2$. k = Coefficient. n = Revs. per Minute. l = Length of Arm. Core. d = Dia. of Armature.	Area Pole to Area of Armature. — to one.	Area Polar Surface to Area of Armature. — to one.
			Inches.	Inches.		Arm.	Com.		Inches.		
Siemens Bros. & Co.	1,530	200	108	21	244,000	5,320	3,420	1·4	·032		
Siemens & Halske	1,000	95	100	20·8	208,000	2,640	2,050	2·0	·052	2·1	3·3
International Electrical Engineering Co.	800	85									
Société Alsacienne de Constr. Mecaniques	750	70	152·5	20	465,000	2,750	2,750	3·9	·024	2·98	5·1
Schuckert & Co.	750	83½	101	16	163,000	2,160	1,460	2·1	·058		
General Electric Company of Creil	700	120	90	20	162,000	2,860	1,970	2·5	·038	2·32	4·25
Societa Esercizeo Bacini de Genes	500	160	116	14	188,400	4,750	1,650	3·1	·017	0·95	2·0
Decauville Co.	400	75	120	14	202,000	2,320	2,260	4·1	·028	2·2	5·4
Postal-Vinay	350	90	64	24	98,250	1,480	1,100	4·2	·041		
Mather & Platt	350	105	80	18·4	117,500	2,160	1,950	4·0	·03	3·1	3·1
Lahmeyer & Co.	350	94	96	16	148,000	2,320	1,920	4·2	·027	1·04	2·4
Ernest Scott and Mountain	330	90	60	20	72,000	1,420	990	3·6	·051	1·86	2·3
De Maubeuge Blast Furnace Co.	280	120	94	20	177,000	2,920	2,230	6·4	·014		
Alioth	225	280	60	14	50,000	4,350	2,740	3·6	·017	1·64	3·8
Société l'Eclairage Electrique	200	110	80	14	90,000	2,260	1,360	5·4	·021	2·9	5·1

TABLE III.

Coefficients, etc., Deduced from Table of Particulars given in Professor Arnold's Book on Armature Windings.

Number.	Maker.	K.W.	Revs. per Min.	Diameter over Armature.	Length of Armature Core.	Diameter squared in Inches Multiplied by Length in Inches.	Peripheral Speeds in Feet per Minute.		Coefficient by Steinmetz Formula :— $\frac{\text{Dia.}'' \times \text{Length}''}{\text{K.W.}} =$	Coefficient from Formula :— Watts = $k \times n \times l \times d^2$ k=Coefficient. n=Revs. per Minute. l=Length of Arm. in ″. d=Dia. of Arm. in ″.	* Ampere Bars per Inch of Circumference.	Current of each set of Brushes.
				Inches.	Inches.		Arm.	Com.				
1	Oerlikon	4·5	1,200	7·2	8·8	455	2,230	1,550	13·8	·0013		
2	Laymeyer	5·0	1,400	7·9	8·0	498	2,900	2,180	12·6	·0072	285	36
3	J. Farcot	14·0	900	11·8	10·2	1,420	2,780	1,840	8·6	·011	252	45
4	Union E. G.	24·0	290	16	12·8	3,280	1,220	690	8·5	·025	266	110
5	Industrie Electrique Carlsruhe... ...	22	190	30	7·8	7,000	1,490	845	10·4	·0164	366/238	200/130
6	Kolben	24	750	15·4	9·6	2,280	3,000	1,570	6·0	·014	352	200
7	Lahmeyer	50	473	24·5	12·8	7,700	3,030	2,500	6·2	·013	282	152
8	Oerlikon	55	600	20·5	14·4	6,050	3,230	1,500	5·2	·015	342	220
9	Koerting Bros.... ...	66	430	51	12·0	31,300	5,800	4,530	9·2	·0049	305	203/172
10	Allioth	75	500	31	14·0	13,400	4,040	2,310	5·7	·012	286	140
11	Union, E. G.	100	180	45	9·4	19,000	2,130	1,020	4·1	·029	470	400
12	Alioth	150	85	79	18·0	112,000	1,750	1,050	9·2	·0157	398	270
13	J. Farcot	150	360	45·5	15·0	31,000	4,300	1,800	4·4	·0134	336	450
14	Lahmeyer	175	150	55	14·0	42,100	2,560	1,790	5·0	·028	390	266
15	Lahmeyer	185	90	157	4·8	118,500	3,700	1,690	4·0	·0172	378/262	236/166
16	Schukert	396	100	86	21·2	156,000	2,260		4·6	·0252	388	200
17	Oerlikon	410	150	93	71·1	148,000	3,650	2,620	3·8	·0184	460	625
18	Oerlikon	560	55	180	16·0	519,000	2,600	1,690	5·0	·0196	446	470
19	Allgemeine	625	105	126	14·0	222,000	3,300	2,240	2·75	·027	522	288
20	Oerlikon	40	700	20	14·4	57,500	3,600	2,430	6·9	·010	270	35
21	Oerlikon	140	250	38·4	24·0	35,400	2,500	1,280	6·6	·0158	290	1,166
22	Oerlikon	220	230	59	21·7	76,000	3,550	2,180	5·7	·0127	244	170
23	Siemens & Halske ...	35	275	33	10·4	11,300	2,430	2,980	9·6	·0113	460	150
24	Siemens & Halske ...	800	65	135	20·0	364,000	2,280	2,550	3·3	·0345	645	800/675

TABLE IV.

Approximate Particulars of a Line of Multipolar Dynamos.

Size Constant $d^2 l$, both in inches.	Ratio of Length of Armature Core to Diameter.	Diameter of Armature Core.	Length of Armature Core.	Suggested Number of Poles.	Kilowatts.	Revolutions per Minute.	Approximate Weights in Lbs.					
							Armature Copper.	Field Copper.	Commutator Copper.	Armature Core.	Magnet Poles.	Yoke.
		Inches.	Inches.									
4,200	0·45	21	9½	4	40	650	150	500	100	500	800	3,000
5,750	0·42	24	10	4	50	600	200	600	125	700	1,000	3,500
7,600	0·39	27	10½	4	60	550	250	700	150	1,000	1,150	4,000
10,000	0·37	30	11	4	75	500	300	800	175	1,200	1,300	4,500
12,300	0·35	33	11½	4	90	450	350	900	200	1,400	1,450	5,000
15,600	0·33	36	12	4	125	400	400	1,000	225	1,600	1,600	6,000
23,000	0·31	42	13	4	175	350	550	1,100	350	1,900	1,800	6,500
32,000	0·29	48	14	6	225	300	700	1,200	500	2,300	2,500	7,000
44,000	0·28	54	15	6	275	250	900	1,400	550	3,000	3,500	8,000
50,000	0·27½	57	15½	6	300	225	1,150	1,600	700	3,500	4,500	8,500
58,000	0·27	60	16	8	325	200	1,350	2,000	850	4,000	5,500	9,000
74,000	0·25½	66	17	8	400	175	1,500	2,500	1,000	5,000	6,000	10,000
94,000	0·25	72	18	10	500	150	2,000	3,500	1,250	6,000	8,000	12,000
145,000	0·24½	84	20½	10	600	125	2,500	5,000	1,500	8,000	10,000	15,000
215,000	0·24	96	23	12	800	110	3,000	7,000	1,750	11,000	14,000	20,000
300,000	0·23½	108	25½	14	1,000	100	4,000	9,000	2,000	15,000	18,000	25,000
405,000	0·23¼	120	28	16	1,200	90	5,000	12,000	2,500	20,000	22,000	30,000

TABLE V.

APPROXIMATE PARTICULARS OF A LINE OF BI-POLAR DYNAMOS.

Size Constant $d^2 l$, both in inches.	Ratio of Length of Armature Core to its Diameter.	Diameter of Armature Core.	Length of Armature Core.	Kilowatts.	Revolutions per Minute.	Approximate Weight in Lbs.				
						Armature Copper.	Field Copper.	Commutator Copper.	Armature Core.	Magnets.
		Inches.	Inches.							
440	1·28	7	9	5	1,200	25	125	12	80	100
600	1·29	7¾	10	7½	1,100	32	170	16	110	120
800	1·29	8½	11	10	1,000	40	210	20	150	150
1,030	1·29	9¼	12	12½	900	50	270	25	200	180
1,270	1·28	10	12¾	15	850	60	320	30	250	210
1,700	1·27	11	14	18	750	75	390	35	320	250
2,240	1·29	12	15½	22	700	100	480	45	400	300
2,830	1·29	13	16¾	27	650	135	550	60	520	350
3,540	1·28	14	18	35	600	200	750	75	640	410
4,350	1·28	15	19¼	45	550	280	950	100	760	470

Number.	Maker.	K.W.	Number of Phases.	Volts.	Revs.	Periodicity.	Number of Poles.	Diameter over Poles
								c.m
1	Helios	3,000	Three and Single	6,600 3,300 2,200	71½	50	84	797
2	Siemens & Halske ...	2,000	Three	2,200	83⅓	50	72	597
3	French Thomson-Houston	1,000	Three	5,500	75	25	40	35
4	Schneider & Co.... ...	1,400	Three	3,000	71·5	50	84	638
5	Oerlikon	1,340	Three	5,500 2,200	94	50	64	49
6	Ganz & Co.	1,200	Three	2,200	125	50	48	413
7	Société l'Eclairage Electriques	1,200	Three	3,000	79	50	76	56
8	International Electrical Engineering Co. ...	750	Three	2,200	83⅓	50	72	55
9	Schuckert & Co.	850	Three	5,000	83⅓	50	72	548
10	Kolben & Co.	825	Three	3,000	90	48	64	548
11	Société Electrique Hydraulique	800	Three	2,200	94	50	64	567
12	Fives Lille	800	Three	2,200	79	50	76	598
13	M. A. Grammont... ...	600	Three	2,400	93¾	50	64	498
14	General Electric Co., London	300	Two	3,000	93¾	50	64	42

TABLE VII.

COEFFICIENTS, ETC., DEDUCED FROM TABLE VI.

Number.	MAKER.	K.W.	Revs. per Min.	Dia. over Poles.	Length of Armature Core.	Diameter Squared Multiplied by Length.	Peripheral Speed over Poles. Feet per Minute.	Coefficient by Steinmetz Formula :— $\frac{\text{Dia.}'' \times \text{Length}''}{\text{K.W.}} =$	Coefficient from Formula :— Watts = $k \times n \times l \times d^2$. k = Coefficient n = Revs. per Minute. l = Length of Arm. Core. d = Diameter over Poles.	Area Pole to Area of Armature. – to one.	Area Polar Surface to Area of Armature. – to one.
				Inches.	Inches.	Inches.			Inches.		
1	Helios	3,000	$71\frac{1}{2}$	314	13·4	1,320,000	5,850	1·4	·0316	·85	1·81
2	Siemens & Halske ...	2,000	$83\frac{1}{3}$	235	23·7	1,320,000	5,100	2·78	·0183	·67	1·0
3	French Thomson-Houston	1,000	75	140	13·5	348,000	2,750	1·89	·053	·74	·74
4	Schneider & Co. ...	1,400	71·5	$251\frac{1}{2}$	10	629,900	4,718	1·78	·0306	·57	·86
5	Oerlikon	1,340	94	197	12·2		4,820			·6	·6
6	Ganz & Co.	1,200	125	163	12·2	324,000	5,330	1·66	·0296	0·718	1·33
7	Société à l'Eclairage Electrique	1,200	79	224	19	950,000	4,620	3·6	·016	·93	1·4
8	International Electrical Engineering Co. ...	1,000	$83\frac{1}{3}$	216	8	373,000	4,680	1·73	·032	·5	·74
9	Schukert & Co.	850	$83\frac{1}{3}$	216	15·8	735,000	4,680	4·0	·0138		
10	Kolben & Co.	825	94	216	15·8	735,000	5,280	4·2	·0118	·75	1·1
11	Electrique Hydraulique	800	94	223	11	546,000	5,480	3·06	·0155	·75	·75
12	Fives-Lille	800	79	235	10	552,000	4,860	3·0	·018	·75	1·1
13	M. A. Grammont ...	600	$93\frac{3}{4}$	197	11	426,000	4,810	3·6	·015		
14	General Electric Co. London	300	$93\frac{3}{4}$	$168\frac{1}{2}$	5·3	180,000	4,000	2·98	·021	·4	·45

TABLE VIII.

APPROXIMATE PARTICULARS OF A LINE OF TWO-PHASE ALTERNATORS.

Size Constant $d^2 l$.	Length of Armature Core in Percentage of its Diameter.	Internal Diameter of Armature Core.	Length of Armature Core.	Number of Poles for a Periodicity of 50.	Kilowatts as Two-Phase on a Non-Inductive Load.	Revolutions per Minute.	Approximate Weight in Lbs.			
							Armature Copper.	Field Copper.	Armature Core.	Poles.
Inches.		Inches.	Inches.							
12,300	16¾	42	7	12	45	500	85	480	1,300	900
17,200	15½	48	7½	14	50	430	100	550	1,500	1,000
23,400	14¾	54	8	14	60	430	110	600	1,700	1,200
30,600	14	60	8½	16	70	375	140	650	1,900	1,500
39,200	13½	66	9	16	85	375	165	750	2,200	1,700
49,200	13	72	9½	18	100	333	200	850	2,500	2,000
70,500	12	84	10	20	110	300	250	950	3,000	2,200
102,000	11	96	10½	24	140	250	360	1,100	3,500	2,500
128,000	10¼	108	11	30	170	200	500	1,600	4,000	3,000
173,000	10	120	12	40	200	150	600	2,100	5,000	4,000
226,000	10	132	13	48	250	125	730	2,700	6,000	5,000
290,000	10	144	14	56	310	107	860	3,200	8,000	6,500

The PRESIDENT: Gentlemen, it is rather late in the evening to begin the discussion. We must remember that the authors of these papers have sacrificed themselves in our behalf by reading the papers so very shortly. If you look at the papers you will find that to-night we have practically gone through one hundred pages of our Journal. Both the papers are full of detail and important matter. Any one who wishes to discuss the papers ought to read them carefully, because there is an immense amount of information in them that has not been read to-night. The President.

The PRESIDENT announced that the scrutineers reported the following candidates to have been duly elected:—

Members.

David Sing Capper.
Albert Neumann Connett.
Walter Bernard Hopkins.
John Beaumont Mitchell.
Charles Remington.
Calvin W. Rice.
Norman Scott Russell.
Guy Lutley Sclater (Com. R.N.)
Charles Felton Scott.
Harold Babbitt Smith.
Charles Weiss.

Associate Members.

James Aitken.
Benjamin John Day.
Colin McKenzie Gardner.
Charles A. Gillin.
George Frederick Gower.
Tom Welbeck Graves.
Edward Stanley Harpham.
Charles Robert Heath.
Frederick Hugh Rothes Neville.
Richard Pape.
Hubert Edward Rogers.
Oliver Cromwell Spurling.
Cecil Strafford.
Frank Walter.
Ludwig Hermann Wilms.

Associates.

William Roger Anderson.
Ernest Brook.
E. A. T. W. Clifford.
James Coxon.
George Wills Cripps.
Robert Napier Cunningham.
Harry Curphey.
Robert Cuthbert.
Damodar Ganesh Dani, B.Sc., F.C.H.
Frank George Evans.
Harold R. G. Forster.
Frederick Alwyn Haigh.
John Cruttall Jenner.
John Kirkwood.
W. A. R. Knight.
Robert Jaffray Nicholson.
William Edward Reath,
Geo. Rob. Wesley Roberts.
Wm. Morrish Selvey, Wh. Sc. A.R.C.Sc.
Thos. Reginald Stancombe.
Frederick Othniel Steed.
Robert Steel.
John William Turner.
Harold Walker.

Students.

James Emile Andrews.
Friend Hartley Beal.
Fred M. Bray.
Roy Apted Broad.
Alec Burrowes, 2nd Lieut. R. G. A.
Robert Harold Chalk.
Geo. Augustin Cladingbowl.
G. B. G. Cleather.
Alfred Craven.
C. A. Henry Edwards.
Roy Remington Elliott.
Arthur Edward Flynn Fawcus.
David Derwent James Fawcus.
Patrick Anthony Gibney.
John Scear Gibson.
Arthur Allan Gomme.
Robert Alfred Ives.
Stanley Jones.
C. Herbert Lange.
James Burne Leefe, 2nd Lieut. R. G. A.
Stanley Harris May.
Alexr. Duncan Melville.
Leopold Geo. Esmond Morse.
Charles Sidney Perry.
Lewis W. Phillips.
John Morgan Griffith Rees.
Cecil Robinson.
Charles Wesley Rycroft.
Harry Robert Speyer.
Harold Stanley Taylor.
Wilfrid Stephen Taylor.
Richard W. R. Twelvetrees.
Frederick Wakeman.
Harry Whitworth.

The Three Hundred and Eighty-eighth Ordinary General Meeting of the Institution was held at the Institution of Civil Engineers, Great George Street, Westminster, on Thursday evening, February 12th, 1903—Mr. JAMES SWINBURNE, President, in the chair.

The minutes of the Ordinary General Meeting held on February 5th, 1903, were read and confirmed.

The names of new candidates for election into the Institution were announced, and it was ordered that their names should be suspended in the Library.

The following transfers were announced as having been approved by the Council :—

From the class of Associates to that of Associate Members—

Walter Ainscough.	Henry F. J. Thompson.
Alfred N. Hazlehurst.	John C. A. Ward.
Francis H. Merrit.	Ernest T. Williams.
John S. Plumtree.	Adolf Schoder.

From the class of Students to that of Associates—

Charles E. Gunner.	Mahmoud Samy.

Messrs. F. C. Knowles and O. C. Spurling were appointed scrutineers of the ballot for the election of new members.

Donations to the *Library* were announced as having been received since the last meeting from Mr. E. Garcke ; to the *Building Fund* from Messrs. F. W. Clements, W. P. Digby, V. M. Gill, M. M. Gillespie, W. W. Strode, G. Walsh, and C. E. Wilson ; and to the *Benevolent Fund* from Messrs. H. J. Glynn and M. M. Gillespie, to whom the thanks of the meeting were duly accorded.

The President.

The PRESIDENT : The Council, in accordance with a suggestion that has been made, ask any members to put forward the names of Members, Associate Members, or Associates they would like to see on the Council, and any suggestions that are sent in before the 12th of March will be considered by the Council. The idea is that the Council might by some chance pass over somebody who ought to be on the Council, and therefore if any of the members suggest a candidate who they think ought to be on the Council, if they will put his name forward, it does not mean that the nomination will be made, but that the Council will consider that name when they are preparing the list of nominations.

We will now begin the discussions on the papers of Mr. Esson and Mr. Kilburn Scott. Will Professor Carus-Wilson open the discussion ?

Prof. Carus-Wilson.

Prof. CARUS-WILSON: With reference to the question of commutation on page 404 of his paper, Mr. Scott says, "Designers appear to be practically agreed that to get sparkless commutation and a minimum zone of movement of the brushes, there must be a certain relationship between the ampere turns required for the air-gap at full load and the cross ampere turn of the armature." He then gives tables, illustrating this statement, obtained from modern standard railway and lighting generators. This view of the sparking question has been accepted as a working hypothesis for many years, ever since Mr. Esson brought it before this Society; but it has given place to other views, notably to that held by American designers. The old view is illustrated by the diagram in Fig. A. This shows the surface of the armature with the fields developed in the usual way, and curves giving the magnetisation due to the fields and armature reaction, also a curve of magnetisation due to the combination of the two with the brush unshifted. The old view amounts to this: that in order to get sparkless commutation, the

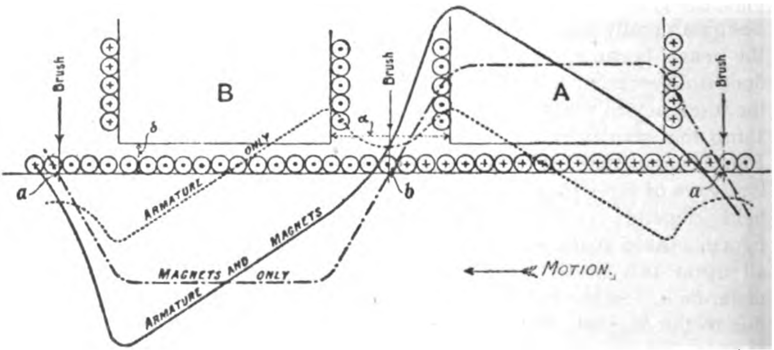


FIG. A.

magnetisation produced by the armature at the pole-tips must be less than that produced by the magnets at the pole-tips.

Now in the 200-kilowatt machine referred to by Mr. Scott, the effect of the armature at the poles is about equal to that due to the field. Thus from the old point of view it is, as Mr. Scott says, surprising that it is possible to get sparkless commutation with the field at the pole due to the magnets completely wiped out by armature reaction. We are not, however, concerned with what happens at the poles, but with what goes on under the brush, and any formula or rule which gives us a relation between the fields produced by armature and magnets under the poles, really does not help us at all. We want to know what it is that goes on under the brush. The field under the pole-tip may be completely wiped out; but so long as we have the right state of affairs under the brush, we may get sparkless commutation. So that this old view of the sparking question, based upon what happens under the poles, is absolutely no guide whatever. The American way of looking at the question is better. It is this: they consider what they call the reactance voltage; that is to say, instead of troubling their heads about what goes

on under the pole-tip, they measure the tendency of a coil to spark by what they call the reactance voltage. Taking that 200-kilowatt machine referred to by Mr. Scott, the reactance voltage per coil under the brush is about 8 volts, that is, they take this as a measure of the tendency of the coil to spark. That is a great improvement as far as it goes. But it fails in this respect: that they then go on to compare this reactance voltage with the average voltage per coil; that is, the voltage between the brushes divided by the number of coils between the brushes. Then it is put in this way: that the reactance voltage must bear a certain relation to the average voltage. In the case of the 200-kilowatt machine already referred to, the average voltage is about 7 volts, and the reactance voltage 8 volts, and the view is that there must be more or less of an equality between these two; that is, if the reactance voltage is high the average voltage must be high, and *vice versa*. Prof. Carus-Wilson.

Now I consider this to be an entirely delusive idea, and that the relation of these two voltages, although it may in a certain type of machine give some indication as to whether the machine is properly designed, really does not indicate in the least what is going on under the brush, because the average voltage is a purely imaginary thing, and does not represent anything going on under the brush that counteracts the tendency to spark as measured by the reactance voltage. The only thing that we can go by is the actual field in which the brush is placed. Fig. A shows that the field produced by the armature under the brush is always of the wrong sign for commutation; and the amount of this field depends practically upon the interpolar distance, a in the figure. As a matter of fact the sparkless running hardly depends at all upon the width of the air-gap, δ, it depends mainly upon this distance a. In the 200-kilowatt machine the induction under the gap due to the magnets is 8,000 lines per square centimetre, the induction due to armature reaction under the pole-tip is 8,600 lines, and the induction under the brush due to armature reaction is equal to 2,600 lines per square centimetre, and is of the wrong sign for commutation; that is to say, so far from having the brush in a field of the right sign for commutation, there is actually a field of 2,600 lines per square centimetre of the wrong sign for commutation.

Comparing the 200 and 250-kilowatt machines, in the former the reactance voltage is 8 and the average voltage is 7; in the latter the reactance voltage is 5 and the average voltage is 5; so that from this point of view the two are practically equal as regards sparking. Yet we find that while in the 200-kilowatt machine there is an induction under the brush of 2,600 lines, in the other machine the induction is just half of that, and the conditions of commutation consequently much better. The reason of the difference is mainly that the interpolar distance in the first machine is only 21 centimetres, while in the second machine it is 32 centimetres.

What I want to urge is this, that this American method of estimating the commutating conditions of a machine by comparing the reactance voltage with the average voltage, though a step in the right direction, does not go far enough. We want to compare the

Prof. Carus-Wilson.

reactance voltage, or the tendency to spark, with the actual magnetic condition under the brush. It is remarkable that sparkless commutation can be effected with the brushes in a strong field of the wrong sign for commutation; if it were not for the use of the carbon brush we could not possibly get the results that we do. The distribution curves of any of these generators or motors show that the brush is commutating sparklessly in conditions which one would have believed to be absolutely impossible. I have some slides showing the results of tests made on a railway motor.

Fig. B gives the magnetisation curves, showing the strong field

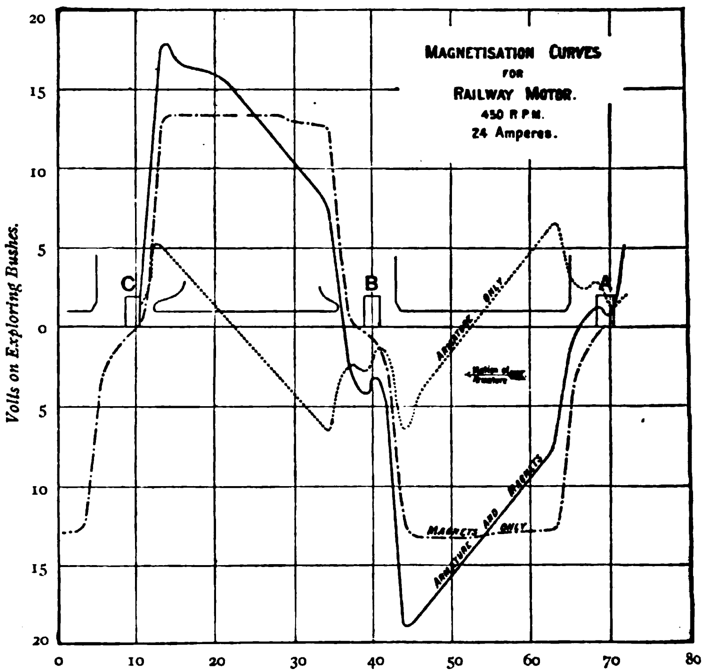


FIG. B.

under the brush due to armature reaction, of the wrong sign for commutation. This motor was being run as a generator, so that the sign of the respective fields are those for a generator. There is a great deal yet to be done on this question of commutation, and if I might throw out a hint to those who have laboratories and money to do what they like with, it would be to investigate with a Duddell's oscillator the condition of current reversal under a brush during the operation of commutation.

Mr. Eborall.

Mr. A. C. EBORALL: I would first of all like to thank Mr. Esson and Mr. Scott for their papers; such papers, together with the discussions upon them, bring out many interesting and useful points,

and are, therefore, greatly appreciated by designers and others interested in the subject. Mr. Eborall.

The first point I would like to refer to briefly to-night is in connection with the question of the "output-coefficient" of standard machines, which has been dealt with by both authors. I have never been able to make much use of the Steinmetz formula given by Mr. Scott, and consider that its utility is limited strictly to standard lines of machinery, all of the same type, and designed upon similar lines with regard to electrical and magnetic constants. Hence, I agree with Mr. Scott that the better known output rule, which takes the speed into account, is to be preferred for preliminary calculations.

I should like to draw your attention to the fact that, in a well-designed series of machines with similar constants, the value of the

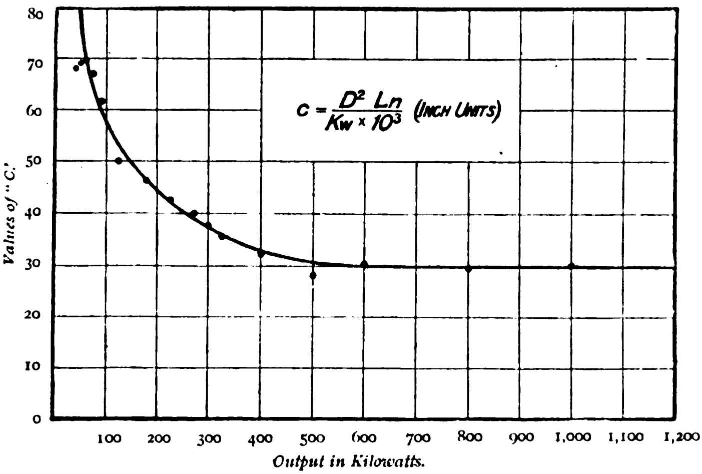


FIG. C.

output coefficient varies in a perfectly regular way, according to the size of the machine. Thus, for instance, Fig. C shows the value of the coefficient for a standard series of modern direct-current dynamos, all built to a certain standard specification; the points lying off the curve, marked by crosses, belong to older types, abandoned because the machines in question had bad "running values." Fig. D shows a similar curve, drawn out for the standard series of machines given by Mr. Scott in Table IV.; in this case, as will be seen, certain sizes might be improved by slightly altering the dimensions or the ratings. Similar curves can be constructed for alternators and induction motors, and are of considerable use to the designer for preliminary calculations.

Referring to Mr. Scott's standard specification for polyphase generators, I would say that, in my opinion, it is not possible to lay down hard and fast rules governing the construction, as Mr. Scott has done, for most cases have to be decided upon their own merits, at any rate with very large machines. For instance, consider the

Mr. Eborall. number of armature slots—in a large machine it will rarely happen that two slots per pole per phase will be enough, and the advantages in employing a larger number in the way of getting rid of harmonics in the E.M.F. wave, and in diminishing armature leakage and noise, will far more than compensate for the slight additional expense. Again, although I am personally in favour of former-wound coils as a rule, yet for certain cases hole windings are superior.

I would next like to correct Mr. Scott's statement that a two-phase generator requires 25 per cent. more armature copper than a three-phase machine. As a matter of fact, as Mr. Esson states, there is practically no difference in the two types,[1] a standard carcase giving the same output, whether as two-phase or three-phase, with the same heating and pressure drop. It is otherwise, however, with two-phase motors, as these are not only larger, but they are some-

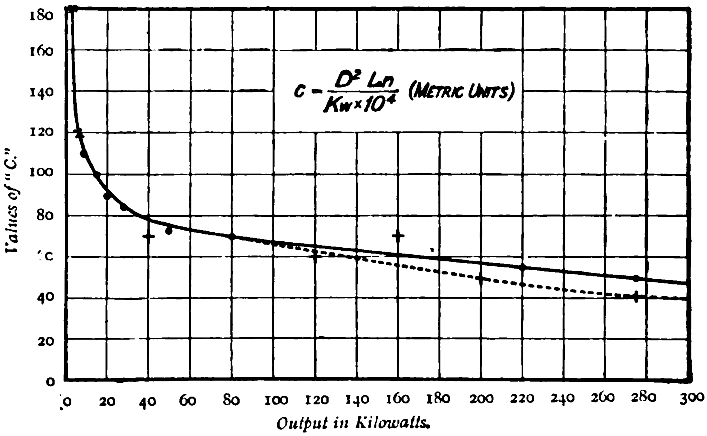


FIG. D.

what inferior to three-phase motors—for instance, a carcase for a 100 H.P. motor must be rated at 90 H.P. for a two-phase motor, the efficiency and power-factor of the latter being about 1 per cent. less, and the overload capacity, before falling out of step, 25 per cent. less.

In reference to high-speed alternators referred to by Mr. Scott, at a given speed the low-frequency alternator has fewer poles than the high-frequency machine; the latter has many poles, and hence the higher the speed the better. As a matter of fact, if there is one fact more certain than any other, in connection with alternator design, it is that the higher the speed the better will be the machine, quite irrespective of the frequency or anything else. For the pressure

[1] Of course, owing to the greater variations in the strength of the armature reactive flux, the armature reaction is relatively a little greater (about 6 per cent.) with a two-phase generator than with a three-phaser. But this small difference, does not, in practice, affect the size or cost of the two-phase machine.

regulation of the high-speed machine is, of course, much better, while the parallel running is much better, firstly, because the cyclic irregularity of the high-speed engine is less, and, secondly, because, with a given cyclic irregularity, the phase displacement of the E.M.F. waves of the machine in parallel is less, on account of the larger pole pitch of the high-speed machines. Mr. Eborall.

In connection with the pressure regulation of alternators, while agreeing with Mr. Scott that it is of importance that the magnetic leakage of the field system should vary as little as possible from no load to full load, if a small drop of pressure is required, yet this is certainly not the most important point to be observed. Of greater importance is the proper ratio of field ampere turns to armature ampere turns, and also the reduction of the armature leakage to a minimum, the proper length of the air gap, and the saturation of the pole shoes and armature teeth. It is only by attending to all these matters that the pressure drop can be kept within reasonable limits, especially on inductive loads, as indeed Mr. Esson has indicated.

Coming now to Mr. Esson's paper, I would first like to say that the A.E.G. machines at Moabit, referred to by him, are certainly not the largest constructed up to date in Europe. I shall be pleased to show Mr. Esson, or any other member, machines nearly 20 per cent. larger, and also nearer home. A machine of 3,500 kilowatts has been working at Willesden for six months, and I am now putting down another. These machines are two-phase, and run at 75 revolutions and 10,500 volts.

I will not now discuss the alternators with braced armature frames, referred to by Mr. Esson (and also by Mr. Scott), as I did so in considerable detail, along with many other matters connected with alternator design referred to by both authors, in a paper published in *Engineering* last June; I would, however, like to make a few remarks on certain other questions raised by Mr. Esson.

I would like, for one thing, to corroborate what Mr. Esson says with regard to "core" transformers; it is indeed a matter of surprise that transformers of any other type are nowadays put down. Not only is the cooling very much better, as a whole, as Mr. Esson says, but no part of the windings gets very hot—with a shell transformer, although the outside parts may be cool, certain internal parts are unavoidably far hotter than is safe, and breakdowns of the high-pressure coils are common from this cause, Then again, a core transformer can be built with butted joints, which I consider an advantage for power work (here the higher no-load current does not matter) because of the ease with which repairs can be executed. Finally, owing to the small winding depth, and to the high reluctance of the leakage paths, magnetic leakage can be reduced to a very small amount, which results in a very small pressure drop, even on inductive loads, as Mr. Esson states.

I am rather surprised Mr. Esson has not referred to the question of cooling in connection with transformers. With large transformers, it is the most difficult matter the designer has to tackle, and it may be said that in order to avoid an excessive amount of material, and an

Mr. Eborall. impaired electrical performance, some form of artificial cooling is necessary with sizes above about 100 kilowatts, while it may often be used with advantage even earlier. There is no time now to discuss the rival merits of oil and forced draught cooling in detail, but I may say that I consider forced draught cooling preferable on the whole, provided the transformers are in a dry place, principally because it is cleaner and more convenient.[1] With very large oil-cooled transformers the oil has to be circulated, or water cooled, and such large amounts of oil in, for instance, a sub-station, are not very nice; again, once the windings of the transformer have been immersed for some time in the oil, it is not advisable to touch them again, as the insulation generally suffers. If a coil in such a transformer burns out, it often means that the whole winding has to be renewed for this reason.

Referring to the compensated motor invented by Mr. Heyland, referred to by Mr. Esson, I would say that the author has made a slip here, as it is a pure induction motor and nothing else. It is simply a single or polyphase induction motor, fitted with a small and and absolutely sparkless commutator, in addition to the slip rings, and differs from the standard motor only in the fact that its power-factor is practically unity at all loads. It works with a rotating field and a short-circuited rotor, just as usual, the only function of the commutator gear being to supply the compensating wattless currents; the speed is synchronous at no load and slips a few per cent. with the load, as usual. I do not think such motors will ever be much used in small sizes, seeing that the cheaper and simpler standard motors have already power-factors of 80–90 per cent., but for large motors, particularly for slow-speed motors with very many poles, the Heyland compensating device is undoubtedly of sound commercial advantage.

Finally, I would like to refer to Mr. Esson's statements relative to the question of the pressure regulation of polyphase alternators. From Mr. Esson's remarks, it might be inferred that he and other designers could, if they liked, actually build a standard line of generators having a drop of only 2½ per cent. on a more or less inductive load, but that this is not the case everybody knows, as it is nearly a physical impossibility to build commercial iron-cored machines with such drops.[2]

Of course, if the alternator is tested upon a load-possessing capacity, such a small full-load drop could be obtained, but not otherwise, and neither Mr. Esson nor any one else can show us examples of commercial standard machines with actual drops of this order. This being so, (and there is no doubt about it whatever), I entirely fail to see the force of Mr. Esson's remarks on the subject of the relative weights of British and Continental polyphase generators.

I must here confess that the knowledge I have of the weights of standard English polyphase generators has been obtained by looking

[1] For pressures above about 15,000 volts, however, an oil-cooled transformer must, as a rule, be employed, on account of other considerations; that is to say, because of the valuable properties of the oil from the insulation point of view. The above remarks are only intended to apply to transformers which have to be used at the more usual pressures of 10,000 volts and less.

[2] I do not of course refer to turbo-alternators and other special types in this connection, but simply to standard machines.

at them, for, contrary to the universal practice on the Continent, not one British maker publishes the weights of his polyphase apparatus. On the other hand, I know from experience that the machinery of first-class Continental firms is quite heavy enough (leaving out such undesirable constructions as those of the braced frame generators described by both authors), and that the performance and construction of polyphase plant, as built by Brown and similar firms, leaves nothing to be desired in the present state of the art. If British machines are, or have been, too heavy (and I doubt this very much) I attribute it to the fact, and I think most reasonable people will agree with me, that the experience of this country in such work is practically nil, compared with that of the Continent. Mr Eborall.

As already indicated, Mr. Esson's drop of $2\frac{1}{2}$ per cent. is an impossibility with a standard iron-cored modern alternator. The best that can be got with such a machine is about 4 per cent. upon a non-inductive load, and 12 per cent. upon a load of 80 per cent. power-factor. But, as Mr. Esson quite rightly says, the Continental machine usually has a 5–6 per cent. and 16–18 per cent. drop under these conditions respectively, and it becomes necessary to see why this is.

I must first point out that Mr. Esson is wrong in saying that small drops of the order he mentions are unnecessary in practice, for nothing would be more desirable if they could be obtained. The successful working of any three-phase lighting and power system depends to a very large extent upon the quality of the pressure regulation—if the generators have large drops the lighting cannot be otherwise than bad, while the performance of the motors will be affected, for the reason given by Mr. Scott in his paper. Again, for three-phase railway work, good pressure regulation of the generators is an absolute necessity, as the following example will show. On a railway with but few trains running, it may quite well happen that the load on the generators varies within a few minutes from zero to full load. At this latter load, the pressure on the terminals of the motors will be normal, and the pressure drops on the system would be about as follows :—

Trolley lines...	5 per cent.	Expressed in terms of the 'bus-bar pressure.
Transformers	4 per cent.	
Feeders...	5 per cent.	
Generators	16 per cent.	
Due to engine governors ...	5 per cent.	
Total	35 per cent.	

So that, for instance, if the full load 'bus-bar pressure is 6,000 volts, then this pressure would be constantly and quickly fluctuating between about 6,000 and 8,000 volts, while that on the cars would vary between 500 and 650 volts, for instance, which Mr. Esson will agree with me is not at all desirable. As a matter of fact, the variation might be even greater than this, necessitating automatic regulators to help take care of it, but the smaller the generator pressure drop, the better will such regulators work.

Close pressure regulation of the generators is therefore highly

Mr. Eborall. desirable, and of the utmost importance. Why, then, are not standard machines designed to give the best possible results as indicated above? Simply because, by doing so, we lay ourselves open to fresh troubles, in the way of parallel running, for with slow-speed engine-driven generators, drops of less than about 15 per cent. are inadmissible except in special cases. The requirements of proper parallel running govern the permissible pressure drop, and nothing else, as several people have found out to their cost.

This brings me to the last point I wish to raise—it is surprising that neither Mr. Esson nor Mr. Scott have made any reference to the compounding of alternators, which is perhaps the most important and most interesting subject engaging the attention of up-to-date designers at the present time. Unfortunately, there is no time to go into this matter now, and hence I would only say that, in my opinion, the most promising solution of this problem is most likely to be found in the employment of asynchronous generators instead of synchronous machines. The difficulties in the way of effectively compounding the latter, not only for varying currents, but also for varying power-factors, are very great, partly because the standard alternator is essentially a machine having relatively high armature reactions. Again, even if a simple method is eventually found, a little reflection will show that difficulties will undoubtedly arise with the parallel running of several compound machines—a totally new set of conditions is brought about, and it is difficult to see how they would ever be overcome.

On the other hand, the asynchronous generator (that is, the induction motor run above synchronism) is a machine which operates by reason of its reactions, and hence the problem is greatly simplified—moreover, as it is asynchronous, it runs perfectly in parallel under all conditions; the operation of such machines is as simple as, and entirely analogous to, that of shunt-wound direct-current dynamos.

And I would like to draw your attention to the fact, that the great value of the Heyland compensating device is in connection with such asynchronous generators, for with its use the machines are made self-exciting, and with a simple addition, they can be compounded or even over-compounded. To give you an idea as to what such machines will do (they are now on the market), I may say that a compounded asynchronous generator of 200 kilowatts, has a pressure drop of under 3 per cent. at full load, no matter what the power-factor of this load may be. There is, of course, no exciter, and the little commutator taking the place of the latter is only 14 inches in diameter, and 6 inches in width, the number of segments being about 100 for a 20-pole machine. This commutator works as smoothly and sparklessly as a slip ring would—in fact sparking cannot arise.

I would like to say much more about these interesting machines and their application, but this is out of the question now. I will merely say, in conclusion, that if our President will allow it, I should be pleased to bring down a small machine and show it to you—perhaps working—one night after a meeting.

Mr. Barker. Mr. J. H. BARKER: Mr. Esson, in his paper, has not referred to what is, and must be, the dynamo of the future, the real high-speed dynamo,

Mr. Barker.

running at any revolutions from 1,000 to 3,000 per minute. The fact that one of 3,000 H.P. can be supplied weighing, combined with turbine, 85 tons, against the ordinary low-speed reciprocator, with dynamo of 400 tons, is enough, of itself, to tempt all builders to embark on the turbine dynamo. Mr. Esson says that as the periodicity in his conductors goes up, the design of a direct-current dynamo increases in difficulty. He fixes the English periodicity at something like 15. The problem that turbine dynamo builders have to face is anything up to 60, and in this country it has been attempted single-handed. It is to be hoped that dynamo builders will come to the assistance of the single-handed, and give the benefit of their experience and brains in turning out a continuous-current dynamo running at this high speed. It is not to the credit of this nation that the large size turbine machines are almost exclusively confined to our Continental and our American neighbours, and it is a subject of grief that the new alternators for the District and Metropolitan railways are not being built by English makers, but by Americans.

It is almost essential now to adopt cast iron for machines where delivery is promised in four months, with a wait of two and sometimes three months for the delivery of cast steel. Cast iron for the dynamo can usually be made on the premises; it would be well if consulting engineers allowed the supply of cast iron in practically all cases. With turbine dynamos the magnet casting is an essential part of the whole machine, and it is absolutely necessary that this part should be almost the first to be used. At present the economic limit for high-speed dynamos for continuous current is about 250 kilowatts. They can be made perfectly satisfactory and to give economical regulation, whilst for continuous running there is no machine which can compare with it.

It is gratifying to hear a man of Mr. Esson's experience approving of the tandem dynamo. By putting one or more dynamos in tandem the speed can be maintained and a highly economical machine as regards steam consumption easily obtained. However, engineers, if shown a tandem machine, will at once rule it out of court.

The drop of alternators has been referred to by the previous speaker, as to which, he says, it is practically impossible to get a lower drop than 4 per cent. In the design of a large alternator as low as 1½ per cent. has been obtained without a very extravagant expenditure of copper in the magnet coils. Such a drop, for practical purposes, is ridiculously low. Recent inquiries show that engineers admit drops even as high as 7 per cent. But if low drops are required, they can be obtained in a high-speed alternator very much more cheaply than in one of low-speed multipolar.

Structural details have been referred to at some length, and it is interesting to hear the experience of slow-speed dynamo builders. The objection to large plates for armatures, 4 feet and 5 feet, have been referred to. But plates over 4 feet cannot be obtained of a much less thickness than 20 mils. For good design for these high-speed machines it is almost essential that there should be nothing more than about 14 mils. The large plates vary in thickness to an appreciable degree. The centre of the plate is tight up and the outside slack, with the usual

Mr. Barker. detrimental results. Plates undoubtedly should be punched and not milled. Punching machines can be bought to-day which will give satisfactory results, and the core built up so true that they need not even be touched with a file, and tubes put through without any trouble.

For insulation there can be no question that paper is much better than any form of varnish or other insulation. The microscopic vibration with a dynamo, and particularly turbo-dynamos, will disintegrate varnish pretty quickly. Paper will last for many years, and in some armatures after continuous service the paper has been practically as good as when it was first put in. As to press-spahn, I have personally had experience of this up to 6,000 volts continuous working with a test of about one and a half times that. It is preferable to micanite or almost any other form. The building up of the tube is in your own hands. More care can be assured that the material is free from any conducting substance, and a very much better article to hand. For drying the author does not object to a temperature of 250° Fahr. It is very objectionable to subject any armatures to such a temperature. A manufacturer of cotton-covered wire, who had carried out exhaustive tests, states that at 70° C. the tensile strength of cotton begins to deteriorate very rapidly. In fact in vacuo drying can be done at a low temperature, and the result is much more satisfactory. The apparatus is not costly; a few pounds will buy a disused boiler which, connected to the works condenser, having half a dozen coils of pipe carrying live steam, gives all that is required.

In conclusion, I would urge on the British manufacturer the necessity for building these high-speed dynamos. It is a pity that more attention has not been turned to them. Representing a firm of turbine builders, I would offer all possible assistance in supplying such engines apart from the dynamos.

Mr. Hawkins. Mr. C. C. HAWKINS: In spite of the fact that the "output-coefficient" in any given line of dynamos follows a regular law, as mentioned by Mr. Eborall, yet I think one must agree with Mr. Esson that on this point there is a surprising divergence between the machines of different makers. M. Rothert, in *L'Éclairage Électrique*, published a careful analysis of most of the alternators at the Paris Exhibition, and found that even in machines of the same order of size this coefficient varied in the proportion of one to four; when two machines, both by good makers and of somewhat the same size, were compared on the basis of one pound of copper being the equivalent in cost of five pounds of iron, the total cost of the active material in the one machine was five times that of the other. This is borne out by Mr. Scott's Table VII., which is mainly derived from the alternators of the Paris Exhibition. The highest coefficient is that of No. 3; but, putting this on one side, owing to its low frequency of 25 as compared with 50 periods in the other machines, the lowest and highest are Nos. 10 and 8, the latter being apparently two and three-quarter times as good from the manufacturers' point of view. There is perhaps rather less divergence in continuous-current machinery, yet one sometimes comes across a machine of exceptionally small size, which no purchaser could question, whether on the score of temperature-rise, of sparkless commutation, or of sound construction.

Mr. Hawkins.

Such divergencies between the machines of firms of equally good reputation, after discounting any great difference of speed or voltage or frequency, can only be traced in the long run to lack of experience or of designing ability, and more often to the former. What we really want is not so much average figures, which are fairly represented by Mr. Scott's tables, but the maxima that can be attained to serve as ideals. One machine which has been seen and proved to be thoroughly good is worth more to the observer than many tables of average results.

Turning to one or two details in Mr. Scott's paper, the roller machine of Fig. 16 was tried by the firm with which I am connected in 1897, but was soon given up, as it was found that it was not so expeditious as the mallet. In the hammering process, when carefully done, there is little danger of damage to the insulation, and in a few moments the bend is imparted to the bar exactly as required, especially at the inner corners of the outer ends.

Mr. Scott says that "it does not appear to have occurred to any one that it is quite unnecessary to bend both ends of each conductor." I think that it has occurred to many people, but the single bend has the obvious disadvantage that the axial length of the end-connectors is then double that of the lozenge-shaped coil, and this is especially disadvantageous if the poles are few in number.

The series-parallel winding of Prof. Arnold has the advantage, as is well known, that the designer can choose any even number of armature paths (two or more) independently of the number of poles. Yet it has always appeared to me that it must labour under the disadvantage that if more than two sets of brushes are employed, there is no automatic corrective to ensure an equal division of the current between the different sets of brushes of the same sign. The current may, in fact, shift from one set of brushes to another and back again, according to the small differences in their contact-resistance which they may offer at any moment. The winding is certainly largely used on the Continent, and I should like to ask any gentleman who has experience of it whether the objection which I have mentioned is in practice really to be feared.

With regard to carbon brush-holders (p. 387), the wording of Mr. Scott's first condition for a successful type would appear to condemn the slider holder as inferior to the hinged-arm holder. If the carbon block is to be fixed at the end of an arm, certainly it should be *firmly* fixed, and the arm should be as long as possible. My own observation has however led me to think that the slider type has a slight superiority due to the fact that the brush is only tossed up and down and not thrown off the commutator surface so as to describe an arc, as it passes over the slight inequalities, almost imperceptible, which must exist between the segments even of the best commutator. Further if Mr. Scott's second condition—that the inertia of the moving part should be reduced as much as possible—is of great importance, which I am rather inclined to question, it is best obtained by making the light carbon block the only portion which moves.

Finally, what has been the experience of Mr. Scott with regard to the vacuum apparatus in the practical drying, not so much of simple

Mr. Hawkins. coils, as of finished armatures, especially after they have been newly painted or varnished? While the vacuum will quickly extract say 95 or perhaps 99 per cent., is there not considerable difficulty in extracting the last one per cent., which really keeps the insulation resistance still low, and is not the process longer on that score than in the old-fashioned stove?

Mr. Sparks. Mr. C. P. SPARKS: On page 331 of Mr. Esson's paper he contrasts single and polyphase alternators as follows:—

> "The drift of practice has been towards making an alternator in all respects satisfactory from an engineering point of view. It must be first and foremost a machine, and a machine that will run continuously without giving trouble."

I disagree with Mr. Esson's views that the single-phase alternator has been abandoned through being unmechanical. Three satisfactory types were developed in this country: the Ferranti, the Siemens, and the Mordey. The reason that single-phase machines are not so largely used as heretofore is due to the change in methods of distribution, owing to the flexibility of continuous current in meeting the varying demands of consumers. This system of supply is now adopted in nearly all large towns, the distribution of continuous current having been materially aided by raising the pressure of supply of three-wire systems to 250/500 volts. In some instances where a town started to supply single-phase alternating current, the system of distribution has been changed to polyphase. In the majority of towns the change has been from single-phase alternating to continuous current, and in cases where the stations are outside the area of supply, polyphase currents are used for transmission to the substations.

Owing to single-phase alternators being unsuited for transmission schemes, we have lost one great advantage possessed by this type of alternator, namely, a comparatively definite wave form. Although polyphase alternators are by degrees being made to give approximately a sine wave, there is great difficulty in obtaining a machine giving as true a wave form as that obtained from all single-phase machines with copper-tape armatures.

Mr. Esson, under the heading of "Conversion," puts before us the relative merits of synchronous and asynchronous motors. In starting a new transmission scheme, either rotaries, asynchronous, or synchronous motor generators can be used for conversion. If the whole energy is transmitted to substations for conversion to direct current, a low frequency (25) will be chosen and rotaries used, but in combined schemes where a certain amount of lighting and power supply is to be given by alternating currents in addition to the supply of continuous current, a higher frequency (50) will be chosen. This frequency cuts out the rotary. As to the relative merits of synchronous and asynchronous motors, if you are supplying alternating current for lighting, as is specially the case in schemes where single-phase systems are being converted, you are bound to use a synchronous motor generator. Mr. Esson himself pointed out during the discussion of Mr. Eborall's paper, the difficulties that arise in controlling the pressure on the H.P. feeders when starting up asynchronous motors. By using synchronous

motors started from the direct-current side you have the minimum interference with the pressure of the lighting system. The synchronous motor generator has a further advantage over the asynchronous, as its speed is independent of small changes in pressure, being governed by the generator speed, whereas the asynchronous motor generator is dependent both on speed and pressure. Mr. Sparks.

The PRESIDENT: Mr. Kilburn Scott has told me that he would prefer not to speak his remarks, but to write them in the *Journal*, as it is getting late. The President.

I propose a hearty vote of thanks to Mr. Esson and to Mr. Kilburn Scott for their papers. The discussion has been exceedingly good. It has not been what you call a lively discussion, but it has been an exceedingly technical discussion, and very valuable, especially to those who are particularly interested in dynamos.

I will, therefore, put it that we carry a hearty vote of thanks to the authors of the papers.

The motion was put and carried unanimously.

Prof. SILVANUS P. THOMPSON, F.R.S. (*communicated*): Many questions of interest are raised by the papers of Mr. Esson and Mr. Scott. These remarks will deal with only a few of them. Professor Silvanus Thompson.

The relation of dimensions to output have often been discussed. The numeric called by Mr. Esson "output-coefficient" and by Mr. Scott "size constant," viz., the product of revolutions per minute by square of diameter and by length of core divided by output (watts), does not appear to be a very satisfactory quantity. For continuous-current machines Mr. Scott gives in Table III. values varying from 0·0013 to 0·0345, so that so far from being a constant it varies enormously. For alternators Mr. Esson gives 0·015, while Mr. Scott in Table VII. shows actual values varying from 0·0118 to 0·053. For continuous-current machines the highest value is 26 times the lowest; while for alternating machines the highest value is about 4·6 times the lowest.

I have found as a much more useful guide to preliminary design the Steinmetz coefficient, namely, the product of diameter and length of core divided by the kilowatts. For the same machines (omitting the first in Table II., which is known to be overrated) the values run from 2·0 to 6·3 for continuous-current machines, where the highest value is only 3·15 times (not 26) the lowest. For alternators Table VII. shows that the values run from 1·4 (for a machine the output of which is also probably overrated), or 1·66 to 4·2.

The "output-coefficient" is based on the assumption that the output of a core is proportional to its volume. The "Steinmetz coefficient" proceeds on the view that the output is proportional to the surface. Mr. Esson makes the remark on p. 338 that "temperature is the factor which limits the output." This, for a given efficiency, is unquestionably true; and as temperature rise depends upon the available surface for getting rid of the heat, the output (for machines of given efficiency) is manifestly determined by the surface and not by the volume of the core; hence the $d \times l$ of the "Steinmetz coefficient" is a truer measure than the $d^2 l$ of the "output-coefficient," in spite of

Professor Silvanus Thompson.

the fact that the former does not take account of differences of speed. In fact, if equal magnetic densities and current densities were observed in the "active belt," the Steinmetz coefficient would simply vary inversely as the surface-speed. Or if surface speeds were all equal, the higher the specific utilisation of iron and copper in the "active belt," the lower would the Steinmetz coefficient be. Mr. Esson's remark on p. 338 that "the so-called active belt becomes more active as the speed is reduced" is misleading, because it refers to engine-speed, not to surface-speed; many of the dynamos which he puts down as slow-speed having, by reason of their large diameter, really high surface-speeds. It is the surface-speed, not the revolutions per minute, which should be considered in comparing one diagram with another.

The reason why $d^2 l$ is not proportional to the kilowatts per revolution, as appears from the figures given by Mr. Scott, is that small machines and large are not worked with the same coefficients of flux-density and of ampere-density at the periphery as large ones: and they cannot be, because of the conditions of ventilation and sparking being different. The proportion is also affected in a way not generally recognised, by the ratio of the armature-surface covered by the pole-shoes to the total peripheral-surface of the armature. Let this ratio, which is the same as the ratio of pole-span to pole-pitch, be called ψ. Then the flux from one pole may be represented by the equation—

$$\begin{aligned} N &= B_g \times \text{pole-face area}, \\ &= B_g \times \psi \times \pi \times d \times l \div p; \end{aligned}$$

where B_g is the mean flux-density under the pole-face, d the diameter of the armature, p the number of poles, and l the length of core parallel to shaft, taken as equal to the axial length of the pole-shoe. Further, the ampere-density per inch along the periphery of the armature, which may be denoted by q_1, if divided by the number of amperes per conductor and multiplied by the periphery in inches, gives the total number of armature conductors Z; or if we write C for the whole armature-current, and c for the number of circuits through the armature, we have—

$$Z = q_1 \times \pi \times d \times c \div C.$$

Now the general formula for continuous-current machines is—

$$E = \frac{p}{c} \times \frac{\text{R.P.M.}}{60} \times Z \times N \div 10^8,$$

and inserting the above values of Z an N and writing $EC \div 1000 = Kw$, we get—

$$d^2 l = \frac{59{\cdot}2 \times 10^{10}}{B_g \times q_1 \times \psi} \times \frac{Kw}{\text{R.P.M.}}.$$

This formula shows at once why the "output-coefficient," as Mr. Esson calls it, is not constant. If we inquire as to the value of the quantities, we find that in modern machines it is not expedient (for commutation reasons) to make B_g *less* than 40,000 lines per square inch, or (for distortion and heating reasons) to make q_1 *more* than 600

amperes per inch run, while ψ is preferably about 0·75. Putting in these figures, we get for the numerical coefficient— Professor Silvanus Thompson.

$$d^2\, l = 33{,}000 \times Kw \div \text{R.P.M.}$$

This corresponds to a value of 0·03 in the coefficients as used by Mr. E. K. Scott.

If we make the further assumption that for cast-steel poles of cylindrical shape, the diameter may be taken equal to l and to half the pole-pitch, with the relation $l = d\,\pi \div 2\,p$, then the substitution of this value gives the solution—

$$d = 7{,}222 \times \sqrt[3]{\frac{Kw \times p}{\text{R.P.M.} \times B_g \times q_1 \times \psi}}.$$

This formula gives excellent figures for machines of this class. Or, if in order to use square poles for laminated pole-cores we make $l = d \times \pi \times \psi \div p$, we shall have—

$$d = 5{,}737 \times \sqrt[3]{\frac{Kw \times p}{\text{R.P.M.} \times B_g \times q_1 \times \psi^2}}.$$

Both the authors comment on the practice adopted by some firms of introducing a resistance of german-silver or nickeline into the commutator risers, a practice supposed to promote sparkless commutation. But neither of them expresses any opinion upon this device, which the present writer believes to be founded on a fallacy. Some makers are equally anxious to avoid any such unnecessary resistance, and are able to produce excellent machines without it. Discussing this point recently with the late Prof. Short, I found him to agree with me.

I have recently expressed my ideas about the design of continuous-current machines in my book on *Design of Dynamos*, and therefore may pass on to practical points. Mr. Scott mentions several modes of insulating core-discs, but does not refer to one that has given satisfaction, namely enamelling them with a wash of water-glass. This is far superior to japan, which is liable to be thrown out when the machine is heated after a long run. I doubt whether sal-ammoniac possesses the property of dissolving iron burrs, which he attributes to it on p. 371. Further, the corroding of copper found to take place in coils treated with shellac varnish must be attributed to the vegetable acids in the lac, not to the alcohol in which it is dissolved.

Mr. Scott refers to the plan (originated by Dobrowolsky) of fitting a thin iron pole-ring or liner around the armature to gradate the magnetic field. The latest improvement on this is a device due to Mr. Murray, not mentioned by either author, of adapting to the pole-cores a ring carrying laminated pole-pieces, in which the stampings are specially disposed so as to secure the proper disposition of field with high saturation at the entrant pole-tip. Messrs. T. Parker & Co. have found great satisfaction with this device.

Mr. Scott's airy disposition of the tooth and slot question on p. 374, by saying that "the simplest way to set out the width of slot and tooth is to make them about the same width at the periphery," will not suffice for the needs of modern good design. A much more detailed consideration is necessary. The recent book of Dr. M. Corsepius shows

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how important this part of dynamo design is—and it runs through all types, alternators and motors as well as dynamos. Mr. Scott attributes the barrel-type of armature windings to Mr. Parsons: but it can hardly have been said to be a success until the two-layer winding was produced by C. E. L. Brown. Mr. Brown also ought to be credited with the device shown in Fig. 17, which he introduced six or eight years ago. It exists in the alternators at the works of M. Baly.

The use of equalising rings as an adjunct to multipolar windings, mentioned by Mr. Scott on p. 379, does not appear to be appreciated by British engineers. In every armature with parallel windings there is, necessarily, if the field-poles are not all of equal strength (and they are not of equal strength if the air-gaps are not alike, even though the cores and exciting ampere-turns are all alike), an inequality in the voltages which they induce, and therefore in the currents they generate. Any inequality in the currents generated in the parallel paths produces two results:—(1) The total resistance of the armature rises; (2) the armature-currents tend so to react as to strive to equalise the fields. The increase of total resistance owing to the unequal distribution of current may seriously affect the heating of the machine, and constitutes one of those obscure causes of waste often vaguely attributed to eddy-currents. Although the point is fairly obvious, it is worth an additional word. Suppose two conductors of 1 ohm each are in parallel. One is apt to suppose that the total resistance of the two in parallel is $\frac{1}{2}$ ohm. So it would be if the whole current divides itself equally between the two. For example, 200 amperes dividing itself equally between them will waste 10,000 watts in each conductor, or 20,000 watts in all; being therefore equal to $(200)^2 \times \frac{1}{2}$. But if for any reason the current were to divide itself unequally, say into 120 and 80 amperes, the heat waste would be 14,400 + 6,400, or in total 20,800 watts; the resistance of the two paths in parallel being not $\frac{1}{2}$ ohm but 0·52 ohm, since $(200)^2 \times 0{\cdot}52 = 20{,}800$. Even so in a parallel-wound armature, the more unequally the current divides itself, the greater is the total resistance offered by the windings. Further, if the current divides itself unequally there will be an undue amount of current to collect at some one or more of the sets of bushes, giving rise to spark troubles. It is mainly to avoid this that in multipolar armatures equalising connections have been found advantageous. They enable the equalising currents of reaction to circulate with a minimum of disturbance to the collection of current at the brushes. This is also the action of the closed-circuit windings devised by Mr. B. G. Lamme for armatures having a series-parallel winding; but these closed windings are quite independent of the ordinary winding, and are not connected in any way to the commutator. With respect to field-magnet windings, it may be pointed out that the "old dodge in telegraphic instrument making" mentioned by Mr. Scott on p. 394 will certainly not effect any reduction of the self-induction of the coils.

Turning to alternators, it may be observed that while Mr. Esson on p. 352 declares high saturation of the field-magnets necessary to good design, Mr. Scott on p. 409 recommends that the pole-cores should have ample area so that the magnetic flux-density may be kept as low as

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possible. In this divergence of view I unhesitatingly take sides with Mr. Esson. Unless the pole-cores are saturated up to, say, from 95,000 to 115,000 lines per square inch, the machine will have a disastrous drop on an inductive load; and the ampere-turns spent on the pole-cores instead of being (as in most continuous-current machines) a negligible quantity compared with those spent on the air-gap, ought to be from 20 to 35 per cent. of the entire excitation. Both Mr. Esson and Mr. Scott assume that the magnet-wheel of a modern alternator may serve as the engine flywheel. This is, to my mind, by no means proven for all cases. The design of flywheel suitable for a given engine may be by no means suitable for the alternator it is to drive; for the most fundamental point in settling the design of an alternator is the frequency of the currents which it is to give. On this depends the number of poles; and as the poles cannot be either enlarged or diminished in their pitch outside certain well-defined limits, the diameter of the alternator is fixed by considerations quite other than those which determine its suitability as a flywheel. With so high a frequency as 50 periods per second it is often difficult to give the magnet-wheel a sufficient moment of inertia for flywheel purposes without making it enormously heavier than the flywheel which an engineer would have designed for the same engine. Mr. Esson is quite right in saying that engineers (and not British engineers alone) have been putting too much material into their alternators. I have in my mind two alternators at the Paris Exhibition for the same output at the same speed, one of which had eight times as much iron (magnetic iron, not including mere construction work) and eight times as much copper as the other. A most exhaustive criticism of the Paris alternators was published at the time by Mr. Rothert, in which this and many other striking facts were brought out. One most distinct fact is not alluded to either by Mr. Rothert in his report, or in either of the two present papers, namely, that in modern alternators having the most diverse properties as to voltage, speed, efficiency, drop, and specific utilisation of material, one thing remains almost constant throughout—namely, the the pole-pitch. And the pole-pitch is almost invariably about 10 inches at the working face. Of the 14 machines in Table VII. of Mr. Scott, all were for a frequency of 50 ∿ save one at 48 ∿, and one at 25 ∿. Their pole-pitches are as follows:—11·8; 10·02; 9·3; 9·4; 9·75; 10·6; 9·3; 9·5; 9·5; 10·6; 11; 9·8; 9·7; 8·3. Leaving out the first (a 3,000 kilowatt) and the last (a 300 kilowatt machine), they all lie between 11 and 9·3 inches, with an average of 9·75. The figure is far more of a constant than any "output-coefficient." In fact, to begin the design of an alternator, the safest way to fix its size is to ascertain from the prescribed frequency and the engine-speed the number of poles, multiply this by 10, and one has the circumference of the working face (in inches). This shows also why, in the desire to have designs that can be built with pole-cores of circular section, the core-length from front to back is so seldom less than 8 or more than 13 inches. Mr. Scott suggests that the length tends for large sizes to remain at about 10 per cent. of the diameter: in which suggestion I do not agree. Mr. Scott refers to the superior strength of magnet-

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wheels built up of two webs of rolled-steel plate instead of having cast-iron arms, and instances the 5,000 k.w. alternators of the Westinghouse Company erected in 1902. An instance nearer home is presented by the alternators built by the late Mr. Gordon for Paddington just twenty years previously. Mr. Esson suggests, on p. 347, that the system of clamping rings and bolts that hold together the armature-core will, if not insulated, form an *amortisseur.* If they do, all that I can say is: so much worse for the machine; for the amortisseur will be entirely in the wrong place. It is wanted on the magnet system to steady the magnetism against pulsations. It is simply harmful on the armature if it acts at all to prevent pulsations of the magnetism at the prescribed frequency.

Each of these papers merits our study; and they mark the recent development of the subject. Mr. Esson's is particularly valuable for its contrasts and criticisms; Mr. Scott's for its numerous practical details, and not least for its references to modern workshop appliances for use in dynamo construction.

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Prof. DAVID ROBERTSON (*communicated*): In Mr. Scott's otherwise most excellent paper the remarks on armature windings (p. 379) are almost entirely erroneous. For a "Parallel Grouping," *i.e.*, a winding with as many circuits as poles, the number of slots and commutator bars need not be even; and for a "Series Grouping," or a winding with only two circuits, they need not always be odd. For the latter winding they may be either odd or even when the number of pairs of poles is odd, although they must be odd when there is an even number of pairs of poles. Similarly, the "Arnold Series Parallel Winding" may have an odd number of segments when the number of pairs of poles is odd. Again, with any practical example of the last winding, which is a singly re-entrant wave winding with as many circuits as poles, if we start at a positive brush and go through as many conductors as there are poles (*i.e.*, nearly once round, or through *four* of the heavy loops in Fig. 18), we do not come back to a segment near to the next negative brush, but to one close to the one we started from, and distant from it as many segments as there are pairs of poles. True, in the example given in the paper we do come exactly to the next negative brush, but this is only because of the small number of segments there chosen. The number of segments (4 for the 8-pole machine) between the start and finish of an incomplete round is the same whether the actual number of segments per pole is 4 or 40, and consequently with the numbers used in practice we return much closer to the brush we start from than to the other. All symmetrical windings, including the "plain series winding," may have as many sets of brushes as poles, and all wave windings may be run with any smaller number, down to two, if desired, provided the brushes be of sufficient width and the segments per pole not too few. Lap windings, on the other hand, must have as many brushes as poles, unless the commutator segments are cross-connected.

With wave windings the conductors are short-circuited through the connections between the several brushes of the same sign, and also, several in series, through the tips of the brushes when these are wide enough. When only two brushes are employed, they must be at least a

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certain width to allow any short-circuits to take place at all. With 8 circuits, as in Fig. 18, the brushes would have to be more than three segments in width if only two are to be employed. With the small number of segments there shown this would short-circuit the whole machine, and would therefore be impracticable, but with the much larger number that would be employed in an actual machine it would be quite feasible. The circuits are more symmetrical when all the brushes are employed, but owing to the way in which the short-circuited coils come in between the several brushes of one sign, the current will not divide equally between them, and its distribution will fluctuate with the phase of commutation. Hence a greater total brush area is required than would be necessary if an equal distribution could be secured. On the other hand, the number of conductors cut out of short-circuit at once is only two with the maximum number of brushes, whereas with only two brushes it would be equal to the number of poles. Better commutation may therefore be expected from the large number of brushes in spite of the greater care required in adjusting them.

In the lap winding, where the several brushes of one sign are not adjacent to one another in the winding, and where the conductors forming one circuit are confined to two adjacent poles, the armature reactions assist in ensuring the equality of the currents in the different circuits and at the different sets of brushes. Against this must be set the fact that each circuit of a wave winding has approximately an equal number of conductors at every pole, and that therefore the balance of the circuits is disturbed much less by inequalities in the polar strengths than in a lap winding. Mr. Scott seems to use "parallel" and "series" to distinguish between lap windings, in which the front and back pitches have opposite signs, and wave windings, in which both have the same sign. The latter terms, lap and wave, are preferable when denoting the mode of winding, whereas the electrical properties are better indicated by the total number of circuits and re-entrances than by the names "parallel" and "series," which do not include all possible cases, and are not used in this connection with a very definite meaning. Thus, the "Arnold Series Parallel Winding" of Fig. 18 would be called an 8-circuit, singly re-entrant, 8-pole, wave-wound drum; an ordinary "Parallel Grouping" for the same field an 8-circuit, singly re-entrant, 8-pole, lap-wound drum; and an ordinary "Series Grouping" a 2-circuit, singly re-entrant, 8-pole, wave-wound drum. The use of the terms "Parallel Grouping" and "Series Grouping" is responsible for the common, but erroneous, notion that these are the only possible arrangements, at least with singly re-entrant windings. It is possible to design a winding to give any even number of circuits whatever with any given even number of poles.

To take only the simplest case, viz., that in which the cycle of the winding is repeated after going through two conductors, or groups of conductors, and their end connections, let[1]

[1] For a proof of these formulæ, and a fuller discussion of the conditions involved, see Robertson on "A General Formula for Regular Armature Windings," *Journ. Inst. E. E.*, vol. 31, p. 933.

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G = Number of conductors, or groups of conductors when a group is treated as the unit.
p = Number of poles.
c = Total number of circuits through armature.
w = Number of separate, but identical, windings, each having c/w circuits.
y_f, y_b = Front and back pitches of winding.
$\bar{y} = \frac{1}{2}(y_f + y_b)$ = Average pitch of winding = Number of times you must go round armature to trace out complete winding.
m = Number of pole-pitches approximately included in the average winding pitch.

Then all these must be whole numbers, and G, p, and c must be even. For any regular re-entrant winding, in which the cycle of connections is completed by going through two groups of conductors and their end connections,

$$\bar{y} = \frac{mG \pm c}{p}, \text{ or } \pm c = p\bar{y} - mG \quad . \quad . \quad . \quad . \quad . \quad (1)$$

$$\text{and } w = \text{H C F of } G/2 \text{ and } \bar{y} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

For ordinary lap windings m is zero, and for ordinary wave windings m is unity. With many poles higher values are possible for both lap and wave windings, but do not seem to possess any advantages to compensate for the greater amount of copper they would require. We may therefore write :—

$$\text{For lap windings, } \bar{y} = c/p, \text{ or } c = p\bar{y} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

$$\text{For wave windings, } \bar{y} = (G \pm c)/p, \text{ or } \pm c = p\bar{y} - G \quad . \quad (4)$$

The individual pitches, y_f and y_b, should be nearly equal to the pole pitch G/p, but it does not matter very greatly what they are so long as they do not differ too much from this, and are not multiples of $2w$. The back pitch is usually taken as the nearest allowable to G/p; other values give chord windings.

Equation (3) shows that for lap windings the number of circuits is independent of the number of conductors, but must be a multiple of the number of poles in order that $\bar{y}$ may be an integer. The number of conductors may therefore be any even number, but it is usual to make it (G) a multiple of the number of poles (p), generally an even multiple, so as to get perfect symmetry of the circuits.

With a wave winding we see from equation (4) that the number of circuits and number of conductors are not independent of one another, but that if c be given, such a value must be chosen for G as will make $\bar{y}$ an integer. This can be done for *any* even value of c whatever. Thus, to get as many circuits as poles ($p = c$), G must be a multiple of p; and for values of c not multiples of p, G must not be a multiple of p.

In going through as many (p) conductors of a wave winding as there are poles, the total travel is $p\bar{y}$, which is equal to $G \pm c$ from (4); c is thus the excess or deficit from being exactly once round expressed in terms of the group space. Expressed in commutator segments, this excess or deficit will be $c/2$ in the ordinary arrangement where there is

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one segment for each pair of groups. Hence the number of circuits is twice the number of segments between the start and finish after going through as many groups and end connections as there are poles.

Equation (4) may be put in the form—

$$\bar{y} = \frac{G/2 \pm c/2}{p/2} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

where G/2 is the number of commutator segments in the usual arrangement, and $p/2$ is the number of pairs of poles. The possible numbers of segments mentioned above for the wave windings follow at once from this when it is remembered that $\bar{y}$ must be an integer.

By allowing a slightly greater latitude in the choice of G, we can arrange to get all the (c) circuits in one winding, or have them distributed over several (w) distinct but identical windings, each of which, however, must have an even number of circuits. The winding shown on Fig. 18 has 64 conductors, 8 poles, and 8 circuits. Hence—

$$\bar{y} = \frac{G \pm c}{p} = \frac{64 \pm 8}{8} = 9 \text{ or } 7.$$

The smaller of these values is the one which applies to the diagram. The H C F of $\frac{1}{2}$G and $\bar{y}$ is that of 32 and 7, which is 1. Hence the winding is singly re-entrant. Numbering the conductors at the bottoms of the slots 1, 3, 5, etc., and those at the tops of the same slots 2, 4, 6, etc., respectively, we see that we go across the back from 1 to 10, and across the front from 10 to 15, giving $y_b = 9$, $y_f = 5$, and $y = 7$, as above.

But by taking G = 72, which is the next highest allowable number and requires four more slots, $\bar{y}$ = 10 or 8. The H C F of 72/2 and 10 is 2, giving a doubly re-entrant winding, each separate winding having 4 circuits. The H C F of 72/2 and 8 is 4, and this will therefore give a quadruply re-entrant winding, each of the four components having two circuits.

When the number of circuits required is a multiple of p, the possible values of G form an arithmetical progression whose common difference is p, and the possible numbers of segments another progression with the common difference $\frac{1}{2}p$. But when c is not a multiple of p, the variety is much greater; the common difference of the progression for G is then the H C F of c and p, but those terms which have a greater factor in common with p must be struck out. It thus cannot be said that the limitations to the possible values of G, and consequently of the number of commutator bars and of slots, is a very great objection to wave windings, seeing that the extreme difference between two consecutive possible values only amounts in the worst case to one conductor per pole, or one segment per pair of poles. The chief place where it will be felt will be in limiting the number of coils which can be placed in one slot. Thus in the ordinary tramway motor armature (a 2-circuit, singly re-entrant, 4-pole, wave-wound drum) the number of segments and coils must be odd. Hence we cannot arrange to tape up two coils together, nor four, etc., although we may do so with 3, 5, 7, etc., if we make a suitable choice of G. Windings having other numbers of

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circuits than two or p do not seem to have been used except with several re-entrances (multiplex windings), and then each separate winding has either two circuits or p circuits. Probably the only reason is that designers are not aware that other arrangements are possible.

The advantage gained by increasing the number of circuits, whether the winding is still singly re-entrant or is made multiplex, is that the amount of current to be commutated at once is reduced. The greatest permissible width of brush is not much altered, because the number of commutator segments must also be increased if any advantage is to be gained by the increased number of circuits. Although the brush spans over more segments, these segments are smaller than before, and there is also a greater amount of space wasted by the mica. There cannot, therefore, be much, if any, room for a saving in the length of the commutator. The gain is in allowing a greater current per pole to be dealt with.

On the matter of commutation (see p. 403) much has been written by many authors. The current which can be collected per pole is limited by two considerations which are not wholly independent. First, we must reverse the current in each section during the time of the short-circuit. This imposes a limit to the product of the current in one section by the inductance of the section. An increase in the number of circuits reduces the first of these factors, and the latter is made as small as possible with the ordinary design by having only one turn per section in all except the very smallest machines. It would, however, be quite possible to exceed the present limits by adding another commutator at the back end of the armature, all the positive brushes on both sides being joined in parallel, and all the negatives. Only one conductor, or half a turn, would then be thrown out of short-circuit at once, with a corresponding diminution of the effect of inductance. The advantage gained by thus doubling the possible number of segments would be considerable with machines dealing with large currents, especially when the brush resistance is the chief factor in effecting commutation rather than the reversing E.M.F. obtained by giving lead. The two short commutators with brushes in parallel would also have considerable mechanical advantages over the single long one of the ordinary design, as the bulging tendency due to centrifugal force is less with the short segments. It would of course cost rather more, but it is worth considering whether it will not pay in machines for very large currents.

The other consideration is that the armature strength should not be so great as to produce too much distortion and weakening of the field. This depends upon the number of conductors per circuit, as well as upon the current per pole, and will therefore depend upon the pressure. It is more important in machines which have no series field coils than in machines with them.

The idea that the armature cross ampere-turns per pole should be less than the field ampere-turns for one gap is based upon the assumptions that a reversing E.M.F. is required, and that the gap is the only reluctance in the path of the armature cross flux. It was originally

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deduced for smooth core armatures. In modern machines with saturated teeth and pole-tips we ought also to take account of their reluctance, and the field ampere-turns available for them should be added to those for the air-gap proper. Making these corrections on the table, page 404, the ratio comes to be much more nearly equal to unity. With careful design it is probably quite possible to commutate properly without a reversing E.M.F. in the coils by making proper use of the brush resistance. This permits of a smaller value of the ratio—

$$\frac{\text{Gap, etc., ampere-turns per pole}}{\text{Cross ampere-turns per pole}}.$$

The effect of the pole span must also be taken into account. Only that cross magnetising current within the pole span is effective. Any outside that produces little effect. Shaping the poles away at the strengthened horn also reduces the effect of the cross E.M.F., and so reduces still further the limiting value of the above ratio.

On page 366 the author states that shaping away the pole right across is not such good practice as shaping it away from the horn to the centre, "because in the middle of the pole the air-gap should be as short as possible." This is very doubtful indeed, as it seems to be based on the assumption that the armature cross ampere-turns produce no effect at the centre. Although true when the air-gap is symmetrical, this is no longer the case when the poles are shaped away. Owing to the variation of the reluctance of the gap, the position of no effect for the cross turns is shifted towards the side where the gap is shortest, the current in the wires there being more effective than that at the other side.

It may be questioned whether high resistance commutator lugs are of any good whatever. They certainly assist the old current to die out, but they also oppose the growth of the new current in the incoming lug. The correct place for the resistance is at the brush contacts, as there the motion gradually cuts it out of the new path from the brush to the winding and adds it to old path. In fact, as their resistance can only diminish the effect of the variation of contact resistance, high resistance lugs are probably more harmful than otherwise.

With regard to the forming of the armature conductors by bending only one end, mentioned on page 377 and shown in Fig. 17, it is probable that many persons have thought of it, but did not consider that its advantages outweighed its disadvantages. It requires about twice as much space for the end connections than does the usual symmetrical arrangement, and requires a considerably greater length of copper with the corresponding increase of the inductance of each section and diminution of efficiency. The more nearly parallel to the end faces of the core the end connections are made, the shorter they will be for a given span, and the less they will project beyond the core. But the slope is limited by the space required for the conductors, and the limiting slope depends almost entirely upon the ratio of width of conductor, or group of conductors, including insulation and clearance, to the pitch of the slots, and will be the same whether the other half is

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straight or bent. The slope must therefore be made twice as long if it has to make the whole span and meet the straight from the other slot, than if the other side is bent over to meet it half-way. With nearly symmetrical end connectors both layers can be equally closely packed together, whereas with one side straight that layer will have a considerable amount of waste space which is not even of much use for ventilation, owing to the closeness of the sloping layer. The straight side certainly has considerable advantages in the matter of threading into tunnels and insulation, but it is a matter for consideration in any particular case whether these are sufficient to compensate for the increased dimensions and weight involved. Fig. 17 seems to show a coil short-circuited on itself. This, of course, is a slip.

The note on page 375 is not quite clear. Under what conditions does the flux distribution curve assume the form there mentioned?

How can the "dodge" of winding all the layers of a coil in the same direction, mentioned on page 394, reduce the inductance of the coil? It will reduce the risk of flashing between adjacent layers by diminishing the maximum P.D. between adjacent parts of them, but it cannot have any effect on the rise of P.D. between the ends of the coil, or on the spark at the switch, on breaking the circuit. Is the author not thinking of the method of winding the coil with smaller wire in several sections which are afterwards joined in parallel? This, of course, would be hardly practicable for the shunt coils of a dynamo, owing to the greater space occupied.

Mr. Mavor.

Mr. H. A. MAVOR (*communicated*): On page 338 Mr. Esson states that the active belt of the machine becomes more active as the speed is reduced, and that he finds little agreement in the output-coefficient between the machines of different makers. There appears to be a little confusion in terms. Mr. Esson's output-coefficient is the reciprocal of $\frac{\text{watts}}{D^2 L R}$. Now I have never stated that I found this coefficient the same between machines of different makers. To make comparison on the lines which I suggested, the depth of slot has to be taken into consideration. If Mr. Esson has the particulars of the machines referred to and will introduce this term into his calculation, I think he will find that the aspect of matters will be somewhat changed.

Professor Silvanus Thompson, in a paper read to the British Association in Belfast, stated that he had examined a large number of machines, and found the results in substantial agreement with the value given to the constant used in my paper, read to the Glasgow Engineering Congress, 1901. The higher value of the output-coefficient on slow-speed machines is probably due to the use of a deeper slot.

Probably the members have not yet had before them a paper read by me to the Glasgow Local Section at their meeting last month, in which it is shown that the energy generated in the active belt, while fairly constant in large machines, is not so in sizes below about 20 ins. in diameter, owing to the increased relative importance of the iron losses in the core. If Mr. Esson could tabulate for the records of the Institution the following information with regard to the machines to which he refers, it would be useful:—

Mr. Mavor.

Total watts output.	Revolutions.
Diameter of core.	Span of poles.
Length " "	Flux-density in the air-space.
Slot depth.	

Of course Mr. Esson is aware that to make a sound comparison between machines it is necessary to specify efficiency and temperature rise. The value of the constant which I adopted in my Congress paper is of course affected by both efficiency and temperature rise.

Referring now to page 352 in Mr. Esson's paper, he states that there is a best weight of copper relatively to the other parts of the machine. My contention is that this best weight of copper may be determined most readily by an examination of the relation between copper and iron in the active belt, and, as Professor Thompson has pointed out, the constant which I used is convertible into ampere-turns per unit cross-sectional area of active belt, so that if this constant be determined by calculation or found by experience, this is exactly what Mr. Esson is looking for. The paragraph to which reference is here made is under the heading "Alternating-Current Generators," but it is none the less true of continuous-current generators, which are of course also essentially alternators.

Mr. Fynn.

Mr. V. A. FYNN (*communicated*): Referring to Mr. Scott's paper first, I will divide my remarks into sections:—

(1) *General Contour:* Mr. Scott's predilection for casting yokes in one piece and afterwards slotting or sawing these through is a very expensive one, and surely unnecessary. There is no difficulty whatever nowadays in obtaining either cast-iron or cast-steel yokes of sufficiently uniform quality; it must be borne in mind that it is good practice to work with fairly low densities in that part of the magnetic circuit, and for that reason it would require very bad castings indeed to make an appreciable difference.

(2) *Poles:* Laminated poles are a distinct advantage and should certainly be used whenever possible; when pole-shoes are reduced in section in order to obtain higher saturation, good results can only be hoped for when that saturation is carried very high to, say, 19,000 or 20,000 lines per cm². It then becomes a question whether this arrangement does not require more ampere-turns than does the usual practice of saturating the teeth, as the path will be longer; the advantage obtained is in any case only a fraction of that due to the air-gap itself, and in order to take full advantage of the armature the teeth must be saturated; the total benefit derived is therefore very questionable. I have never found that a slot which does not cut pole and yoke clean in two is of any use to prevent cross-magnetisation. Machines which require adjustable pole-tips in order to commutate sparklessly rely on the leakage-field from the pole-tips, and cannot therefore commutate sparklessly at all loads with fixed brushes. A modern machine should not be designed on these lines, but should be figured to commutate sparklessly in the neutral zone, in which case all that is to be guarded against is a distortion of the field sufficiently extensive to disturb this neutral zone materially. This object is not difficult to obtain, and may

Mr. Fynn. easily be achieved by symmetrical arrangements allowing of equally good performance when running in either direction and either as motor or dynamo.

(3) *The Armature Core:* Mr. Scott's proposal gradually to decrease the diameter of the plates in order to avoid the straggling appearance of the ends involves great risk of breakdown; a number of very sharp corners are thus formed which can easily cut through to the wire, especially as the plates, not being compressed tightly at those points, are liable to move. The teeth should all be well supported to within, say, a ¼ in. of the armature circumference. Brass end-plates answer the purpose very well. It seems to me that plates should either be slotted, annealed after slotting and assembled, or assembled in the shape of discs and the slots then milled out. A combination of both methods is surely waste of time, as it involves setting for both operations.

(4) *Shape of Slot:* I must differ from Mr. Scott when he says that the shape of the slot is not so much a question of electric dimensions as of machining. The dimensions of a slot have the greatest influence on the proper commutation of a dynamo, and all we can do is to satisfy mechanical requirements as far as commutating will permit. I am, of course, referring now to machines giving the greatest possible output for the least weight. In such machines closed slots or tunnels are out of the question. I can recommend from experience the method Mr. Scott now suggests for holding the wires down in the slots by means of metal wedges (his Fig. 13 E). I have used this very plan for the first time on a 150 k.w. machine designed in September, 1901, with the best results; the wedges were of brass.

(5) *Winding of Armature:* Even heavy section bars can be and are often partially formed; being bent at the pulley-end round a mandrel, anything conducing to a reduction of solder joints is to be welcomed. I feel certain that many people must have found that it was not necessary to bend both ends of each conductor in order to complete a winding, and most of them probably abandoned the idea because it doubles the amount of room occupied by the end windings, and adds some 50 per cent. to the weight of idle copper. Nevertheless, I know of instances where this style of winding has been used. Space and money were no object.

(6) *Internal Circulating Currents:* There is no doubt that parallel-wound or multiple-wound armatures are liable to get out of balance electrically; it is, however, no less certain that balancing connections or separate balancing windings offer a perfect cure when coupled with judicious dimensioning. As regards the series-parallel system of winding armatures, it has always been put forward by its votaries that its main advantage over the multiple system lay in its total indifference to inequalities of air-gap or pole-strength or other unbalancing influences. I see now, however, that notwithstanding all this, Mr. Arnold has taken out patents covering the application of balancing connections for these series-parallel windings.

(7) *Commutators:* The use of high resistance metal for commutator lugs has been greatly abused. That device is often of real value in order to make a machine less sensitive, but often also it is useless. It

is, however, easy to predetermine by calculation when benefit can be derived from it. Mr. Fynn.

(8) *Brush-Gear:* I am sorry to find that the author has said so little about brush-gear, that most vital part of a dynamo. I regret this the more as his ideas on the subject seem to differ from mine entirely. The brush-gear which I found to answer best is one in which the carbon block only moves, and that block should be positively connected by a flexible strip of ample section to the holder-body in such a way as not to hinder the free movement of the carbon. The blocks should be enclosed in a box. This makes the moving part as light as possible. There is no reason whatever for making the width of the carbon equal to a whole number of segments.

The author's ideas as to the design of direct-current machines must be very different indeed from mine, as I find that only the fewest of the figures which he gives as general come anywhere near my standards. Mr. Scott lays great stress on the relationship between ampere-turns required for air-gap and cross ampere-turns in relation to the commutating properties of a dynamo. In my estimation this relation has only a very secondary effect. I have designed several machines which will run absolutely sparklessly with full-load current at full speed when the voltage is reduced to $\frac{1}{10}$th of its normal value, in some cases even to less, and I find it quite easy to work with above relation at less than unity. I happen to have before me the data of a 65 k.w. dynamo of mine forming one of a series, which runs at 750 revolutions and commutates sparklessly with fixed brushes for all loads, the final temperature rise being 79° F. Although only a small dynamo, its constant for the "output equation" is ·0386, and compares therefore favourably with Mr. Scott's constant for flywheel generators. The "circumferential current-density" is of course high, but this figure just falls within the given limits, being 660, that is near the values given in the paper for very large generators. I think it is very necessary when setting up any such constants to differentiate between dynamos built for different voltages, and only compare machines showing the same temperature rise and commutating properties, to be really of value for the purpose of comparison, these constants should apply to machines similar in those respects. In addition, in order to be quite exact, the comparisons should be based not so much on revolutions per minute as on peripheral speed, as the output for a given temperature is closely associated with this figure.

(9) *Alternators:* The "tie rod" construction has certainly seen its best days, and is being now abandoned; in its place we have the far better "angle iron construction," which no doubt has come to stay, as it really solves a difficult problem, and I am surprised that Mr. Scott has omitted to mention it. With regard to the new Niagara Alternators and the foot-note relating thereto, it is also interesting to note that Mr. C. E. L. Brown had originally proposed an inner pole machine for that station, and has always been of opinion that it was the best type for the purpose.

(10) *Voltage Drop:* Mr. Scott omits to mention the armature-self-induction which is the principal cause for reduction of voltage at full

Mr. Fynn. load; the same considerations apply here as in the direct-current case. Surely the lower the periodicity required the easier it is to adopt slow speeds, and the higher the periodicity required the greater advantage is there in high speeds. To make the comparative figures in the tables of greater value the "regulation" properties of the alternator would have been of interest. This additional information would, no doubt, account for the apparent discrepancies. It is also not fair to compare alternators designed for a widely different periodicity and widely different terminal voltage. It has given me much pleasure to read Mr. Scott's very interesting paper, and it should call forth an instructive discussion.

Passing now to Mr. Esson's paper:—When speaking of the Frankfort Exhibition of 1891, and whilst complaining of the scarcity of alternators shown, Mr. Esson forgets to mention what was surely one of the features of the show, namely, the Brown three-phase machine. Although it is a design which, like others, has since disappeared, it did create at the time a great deal of interest and found numerous imitators. Had Mr. Esson noticed this alternator at the time, he would have found that there was practically no variation of flux for varying positions of the field, and he might have designed the improved alternators he brought out in 1895 several years earlier.

The statement that there is no essential difference between the self-induction of a coreless and an iron armature, I put down to a *lapsus linguæ*. Surely this point is clear enough at the present time.

I agree with Mr. Esson when he says that the "slider form" of brush-gear is most in favour. It is very justly so. I like to see the arm, however, as short as possible—in fact the whole appearance approximating that of the "reaction holder." The "hinged holder" type is decidedly faulty, and can only be used with some measure of success on commutators of very large diameter.

I notice that neither author has a good word to say for the so-called inductor alternator. Unfortunately time does not permit me to go into this matter very fully just now, but I may say that my experience with that type has been very satisfactory, and I have designed quite a number which in total weight are only very little behind the best heteropolar designs with all poles wound, whilst in cost they are distinctly more advantageous, comparing machines of equal drop. Commercial machines ought to have from 4 to 6 per cent. drop for a power-factor of one. I know of no alternators working in this country with only 2½ per cent. drop at full load, and until quite recently our alternators here showed all a drop of nearer 12 than 5 per cent. The so-called inductor alternators are, however, not suitable for outputs exceeding, say, 2,000 k.w. at 1,000 revolutions as three-phasers, the main exciting coil becoming unwieldy in larger sizes.

Let me hope, in conclusion, that the downfall of the single-phase system, surely the simplest in existence, is not so near at hand as Mr. Esson's concluding remarks may lead one to believe. The new single-phase motor which I have designed, and which is being now thoroughly tried, may, I hope, be of great help to those stations who at this moment are only waiting for sufficient capital to change over to two- or three-phase, sometimes even to direct current.

Mr. H. LEDWARD (*communicated*): With regard to the output-coefficient of Mr. Esson, I should like to make a few remarks. From the formula for the voltage of a continuous-current machine, it is easy to develop the following formula (using inch units)— Mr. Ledward.

$$\frac{\text{K.W.}}{\text{D}^2\text{ L R}} = 1{,}67\ a\ .\ \text{B}\ .\ \text{A S}\ .\ 10^{-10},$$

wherein a is the ratio of pole-arc to pole-pitch, B is the flux-density on the face of the pole-shoe, and A S is the number of ampere conductors per inch of periphery. This formula, it should be noted, is not empirical, but is fulfilled absolutely in all machines. The output-coefficient is hence dependent upon the values of a, B, and A S, which are in turn fixed by the necessity for sparkless commutation and are independent of the frequency. The explanation given by Mr. Esson for the higher output-coefficient of Continental machines is therefore incorrect. The fact is that they customarily go a little higher with the value of A S and, perhaps, B. I do not, moreover, think that Mr. Esson is correct when he states that the frequency of Continental machines is lower than that of English machines; if anything, the reverse is the case. The average value of c for twenty machines (of Continental make) varying in output from 55–1,000 k.w., I have found to be 16,85. The maximum and minimum values being 35 in the case of a 100 k.w. machine of V.E.A.G.-Wien, and 7 in the case of a 350 k.w. machine of the Soc. Alsacienne.

With reference to the output-coefficient, I may mention that the output-coefficient of an alternator is—

$$\frac{\text{K.W.}}{\text{D}^2\text{ L R}} = 1{,}67\ a\ .\ \text{B}\ .\ \text{A S}\ .\ k\ .\ 10^{-10},$$

where k is the E.M.F. wave-factor $= 1{,}11$ for sine wave-form. I do not think that Mr. Esson is correct when he states that the output-coefficient of Continental alternators is about 0,015. I know machines the output-coefficients of which vary from 0,036 to 0,008, the first being a 300 k.w. of the Soc. Alsacienne, and the latter a 275 k.w. machine of Brown, Boveri & Co. This variation is, I think, considerably greater than is the case with modern continuous-current machines. For example, from 10 c.c. machines varying from 330–1,000 k.w. output, the output-coefficient varies irregularly from 0,053 to 0,026.

With regard to transformers, the shell type is undoubtedly cheaper and more efficient, and with a reasonable system of forced draught cooling, such as is employed by the Westinghouse and the General Electric Company, they are preferable to the core type for all large sizes (say above 100 k.w. per phase). They cannot, however, be easily built for more than one-phase, which explains the fact that the Americans prefer three single-phase transformers for three-phase work.

I think that one reason for the use of the special type of rotor winding mentioned in Mr. Esson's paper is that the ordinary type of squirrel-cage winding is patented by the A.E.G. in Germany.

Mr. E. V. CLARK (*communicated*): In connection with speed and periodicity, it is perhaps worth while to call attention to the fact that, Mr. Clark.

Mr. Clark. for a given periodicity, the linear distance between pole centres is dependent on the peripheral velocity of the machine, and on nothing else. This proposition is self-evident directly it is looked into, though I cannot recall having seen it in print. At 50 cycles, for instance, each armature bar must pass over 100 poles per second. If, then, the poles are 1 foot centres, the peripheral velocity must be 100 feet per second, or 6,000 feet per minute; and one can only reduce this to 5,000 feet per minute by crowding the poles in to 10-in. centres. As high speeds are associated with high peripheral velocities, it is in this class of machine that one finds the poles most widely separated.

In this connection, it may be pointed out that Mr. Esson is very conservative in fixing 6,000 feet per minute as the maximum advisable limit (*vide* p. 340). The E.C.C. 1,500 k.w., 50 cycle two-phase alternators in the new Leeds generating station run at 200 revolutions per minute; and the magnet-wheels, 13 feet 6 inches in diameter, have the great velocity of 8,480 feet per minute, with a polar pitch of almost 17 inches. It is almost impossible (except with low periodicities) to avoid a high peripheral velocity in machines of large output, simply on account of the crowding of the poles which otherwise results, and the inefficient use of materials when the magnetic path is several times as long as it is wide; and of this, the 3,500 k.w. Kolben alternator at the Willesden station of the Metropolitan Electric Supply Company, Limited, affords a good illustration. This machine, of which particulars have courteously been supplied me by the company's secretary, runs at 75 revolutions, generating two-phase current at 60 cycles, and its armature is 300 inches in bore, and 29½ inches in axial (core) length, the output-coefficient being ·0176—considerably smaller than one might have expected at first sight. But Mr. Eborall mentioned that the design of this machine was rendered far from easy by the high periodicity, and a little scrutiny will fully bear this out. Even with this large diameter, giving a peripheral velocity of about 5,900 feet per minute, the polar pitch is under 10 inches, and this with an axial length of pole of 29½ inches or thereabouts. In antithesis to this, we have the three-phase machine of the same speed and output, but generating current at 25 cycles, built by the General Electric Company of America, and illustrated in Fig. 28 of Mr. Scott's paper. Here the diameter over poles is reduced to 200 inches—but two-thirds that of the Willesden alternator—with a reduction in peripheral velocity to 3,900 feet per second, but nevertheless the polar pitch, on account of the low periodicity, is 15·6 inches, affording a much more satisfactory and efficient shape to the section of the magnetic path. The design of a 3,500 k.w. alternator at 75 revolutions for a periodicity of 100 is difficult to conceive. In fact, it is doubtful if any maker would be anxious to undertake to construct a machine of this output and periodicity, except perhaps for coupling to a steam turbine.

Mr. Bowen. Mr. H. V. Bowen (*communicated*): I have read Mr. Scott's paper with great interest. Referring to the section "Winding of Armature," it would have been of great interest to many English designers if Mr. Scott had extended this section and favoured us with his experience and criticism of some of the uncommon Arnold Series Parallel Windings,

which no doubt he would have met, being so closely associated with the International Engineering Company. It is well known that these types of windings are very much in vogue on the Continent, particularly employed by German manufacturers. It would be interesting to know if these types of windings, arranged on slotted armature cores and without balancing rings, are altogether a success as regards sparkless commutation and the absence of internal circulating currents, assuming a normal ratio of armature ampere-turns to field-ampere turns. To clearly indicate the type of series parallel windings I refer to, I give the following data of some dynamos of various German firms, the first two being taken from Table I. Mr. Bowen.

EXAMPLES OF ARNOLD'S SERIES PARALLEL WINDINGS.

Voltage.	K.Ws.	Revolutions per minute.	No. of Poles.	No. of Armature Circuits.	No. of Lines of Brushes.	Total No. of Conductors on Armature Periphery.	No. of Segments in Commutator.	Pitch of Armature Conductors.	No. of Slots on Surface of Core.
550	1,000	95	14	10	14	1,144	572	81	286
550	350	94	12	6	12	1,218	609	101	609
550	165	400	8	4	8	500	250	63	250
500	650	90	30	10	30	2,020	1,010	67	505

The last machine is very interesting, as it possesses several uncommon features. It is a direct-coupled steam set, and literally a flywheel type generator, the armature core being built on the top surface of the heavy cast-iron flywheel. The machine was manufactured by the Helios Company, Köln, Ehrenfeld, for operating machinery in a cement works in Hanover, I believe. The following are some of the dimensions:—

Diameter over the armature stampings ... 5,000 mm.
Width over core stampings ... ... 210 „
Diameter over the field system, exclusive of the extra for yoke feet ... ... 6,100 „
Diameter of Commutator ... ... 3,000 „

There are 505 slots on the surface of the core, each 16 × 42 mm., and there are four armature conductors per slot, each 4·5 × 12 mm. The brush gear is supported from the yoke by four brackets.

I should like to ask Mr. Scott if he has met with such an uncommon example with Arnold's Series Parallel Winding, and if so, his critical remarks upon the observed behaviour of the machine.

Referring to these types of windings, I have in mind two 100 k.w., 230 volts, 6 pole generators, both having series parallel type of armature

Mr. Bowen. winding. These machines were built by a prominent German firm, and who are at the present time offering very cheap machines upon the English market. These two machines, even when running at half load, became very hot on the armature, and sparked badly. Probably the risks attached to these types of windings have prevented English and American designers from adopting them, and it would be very interesting, I am certain, to the members of the Institution who are in touch with the designing of generators, to hear Mr. Scott express his opinion upon these uncommon windings.

On page 379, Mr. Scott states that "in ordinary parallel winding the number of slots and commutator segments must be even, whereas in series winding the numbers must be odd." If the armature be loop wound, a parallel winding will result, no matter whether the number of commutator bars be even or odd; and again, in two circuit series windings, if the number of pole pairs for the magnetic circuit be odd, a series winding can be obtained by an even number of commutator segments, as shown by the data given below of a 6 pole 75 k.w. generator, which I designed some time ago.

On page 400, and in the last paragraph, Mr. Scott states that if the "circumferential current density" is about 700, it indicates a skimped design. I would like to point out that this figure must be reached, and sometimes must be exceeded if the machine is of large capacity, running at a high speed, otherwise the iron losses will far exceed the C^2R losses of the armature, with the result that the all-round efficiency will be reduced; so that under certain conditions this figure cannot indicate a skimped design. Of course, in the case of generators which run as shunt machines at 460 volts for lighting purposes and 550 volts for traction purposes, with a constant kilowatt output and speed, this circumferential density must be reduced on account of the weak field and large current under the shunt conditions and the consequent introduced sensitiveness of the non-sparking range.

On page 403, Mr. Scott states that the average figure for the amount of current which can be collected at one pole can be taken at 500 amperes per pole. This figure, I think, would be high for high-speed traction generators, and I am afraid that in the majority of cases, if traction and lighting generators with slotted cores were designed on these lines, their behaviour would not be altogether desirable as regards sparkless running with fixed brush position on variable loads.

On page 404 are given some extracts from Messrs. Parshall & Hobart's book on Electric Generators, in which the gap ampere turns divided by cross ampere turns are between ·61 and ·68. With such a ratio as this, and if the machines were shunt-wound and self-exciting (the generators as a matter of fact being compound-wound), the variation in terminal voltage through varying loads would be considerable.

I may state that one of the manufacturers of these machines, according to one of their recent designs, has now adopted a ratio of over unity. This ratio would be a far better factor for indicating skimped design than "circumferential density." A ratio less than unity really means a machine very much overloaded.

Table I. supplies much interesting information with respect to

Mr. Bowen.

various makers, representing different characteristics and constants of design, and I give below data of a few machines which I have designed for the Industrial Engineering Company, of Newton, Hyde, at various times. These figures may be of interest to those perusing Table I.

DATA OF THREE HIGH-SPEED DIRECT-COUPLED "INDUSTRIAL" GENERATORS.

	K.W.	550	250	75
	Amperes	1,000	770	137
	Volts	550	325	550
	Revs. per minute	330	380	500
Winding	Armature	Drum	Drum	Drum
	Field	Compd.	Compd.	Shunt
	No. of Poles	8	8	6
Armature	Diameter of Armature	54	44	28
	Length of Core	11½	10½	6½
	No. of Slots	168	192	131
	Core Section	180	120	68
	No. of Conductors	1,008	768	524
	Section of Conductors	·075	·065	·03
Field Magnets	Section of Pole	140	90	53
	Polar Surface	170	130	72
	Air Gap	7/16	9/32	3/16
	Section of Yoke	190	125	72*
	Poles	Solid	Solid	Solid
Commutator	Commutator Diameter	36	30	19
	Commutator Face	12	12	4
	No. of Segments	504	384	262
	No. of Brushes	8 sets each of 8	8 sets each of 8	6 sets each of 4
Weights	Armature, Copper	1,060	630	150
	Field, Copper	2,300	1,650	540
	Commutators, Copper	1,000	860	200
	Armature Core, Iron	3,500	2,000	700
Net Efficiencies	Full Load	95·5	93·5	92·5
	¾ Load	95	93·0	92
	½ Load	93·5	91·25	90
	Circumferential Density	750	540	420

* All the yokes are of cast iron.

Note.—All dimensions and weights in inches and pounds.

The working characteristics of the machine are quite satisfactory in every respect, the temperature rise keeping well within the usual limits, and no sparking taking place from no load to 25 per cent. overload, with fixed brush position, and further capable of taking 50 per cent. momentary overloads without injury.

Mr. Esson.

Mr. W. B. ESSON: I am glad to say that in replying to the various criticisms that have been passed upon my paper my task is a comparatively light one. The first speaker, Professor Carus-Wilson, re-

Mr. Esson. ferred to the question of commutation, and it would seem with regard to this matter that the more we know the less we really learn about it. We used to think some ten years ago that we knew about it all there was to be known, after the classical papers of the late Dr. John Hopkinson and others had been read. There had to be a fringe of magnetic lines at the pole-tips which allowed the current to be gradually stopped in each section as it came under the brush and induced in it a current in the opposite direction just of the proper magnitude before the section left the brush. The latest exponent of the American view is, I suppose, Mr. Hobart, whose excellent paper read at the Glasgow meeting is still fresh in our memory, but so far as I am aware Mr. Hobart does not find fault with the old theory. The argument, I take it, is this. You probably want some kind of fringe for bringing the current in the section to zero and reversing it, but the magnitude of this fringe must be dependent on the reactance voltage. Make the reactance voltage negligible and then you can be independent of the fringe, or in other words you can do without a positive field and work, as Professor Carus-Wilson says, even with a negative one.

In some of his dynamos I understand Mr. Hobart has a reactance so small that he can run them with a trailing instead of a leading brush, thus making use of what would otherwise be the back induction of the armature for strengthening his field. In this case it becomes, of course, forward induction. I have pointed out in another place[1] that when the armature teeth are highly saturated, the *real* air-gap by no means corresponds with the *apparent* air-gap, so it is just possible that in the cases cited by Professor Carus-Wilson the field under the pole-tips is not really but only apparently reversed. However that may be, it is certain, as the speaker says, that without carbon brushes we could not in modern machines get the results we do. As Mr. Hobart points out in the paper referred to, the idea of reactance is not new, and when the matter is looked carefully into, reducing the reactance voltage really means making the commutator sections for a given machine as numerous as possible. In large output machines where we are reduced to two bars per commutator section, the current in each bar must be restricted to about 150 amperes, and the number of the poles must be settled so that this current per path is not exceeded.

Coming now to Mr. Eborall's remarks, I understood him to say that the output-coefficient for a consistently designed line of machines varied in a perfectly regular way. I quite agree with Mr. Eborall that if there is variation, this should be and would be regular; at the same time there may be no variation at all in the coefficient, as witness the line of machines proposed by the late Professor Short to which reference is made in the paper. All these machines have a similar output-coefficient from the highest to the lowest. In a consistently designed set of machines, then, the line connecting the size of the machine with the output-coefficient may vary from a straight line to a curve of regular form according to the idea of the designer, but consistency is not of course to be expected when comparing machines by different makers taken at random.

[1] *Journal of the Institution of Electrical Engineers*, vol. 31, page 239.

Mr. Esson.

The above remark answers some of the observations made by Professor Silvanus Thompson, who complains about the variation in the output-coefficient. Talking of the Steinmetz coefficient, I have never used it or felt the need of it, due no doubt to my attacking the design from a starting point which did not make its application convenient. I do not agree with Professor Thompson when he says that my remark that "the so-called active belt becomes more active as the speed is reduced" is misleading, because this remark has reference to an armature of given size, and it is plain, therefore, that in this case speed is synonymous with surface velocity. Again, the d^2l coefficient expresses quite correctly the output according to the product of the total surface and the surface velocity, though for convenience the equation is expressed in terms of revolutions per minute. It is merely a matter of substituting a term for surface velocity instead of diameter × revolutions per minute and altering the coefficient to correspond, but as every one talks of revolutions per minute, in the form given the expression appears more serviceable. Whichever is preferred, the fact is not altered that as you reduce the speed of a given armature you can press up the induction and so increase the output for the same heating, which brings us back to where we started, namely, that with reduced speed there is more activity in the active belt. It can be shown with regard to this activity that the condition for getting maximum results is that the weight of the iron in the core teeth must be about equal to the weight of the copper in the slots.

Mr. Barker's remarks on turbine generators are extremely interesting, but I do not think that weight *per se* has much to do with the matter. Once erected in a generating station, the set has not to be shifted annually for the spring clean, so that whether it weighs 85 or 400 tons is only of importance in that it may affect the cost. The kind of workmanship in a turbine is different to that in an ordinary engine, and the real question as to superiority will be decided by the cost of the two classes of machinery in the long run. That the turbine has attained great success is undoubted, and one cannot regard with too much admiration the man who in the face of scorn, opposition, and ridicule has by his persistent effort and mechanical genius brought this machine to its present high state of perfection. All this I may say while confessing that turbines always get on my nerves. When I enter a station where turbine generators are running I have only one desire—that is to get out again. The noise and general air of feverish restlessness about the place worries me, whereas when I go into a station equipped with slow-speed plant, where fine engines are running with quiet and dignity, there is a feeling of calm about the whole which strongly appeals to me. That, however, may be merely a matter of temperament.

I don't approve of the tandem dynamo, if Mr. Barker means by that two or more armatures threaded on the same end of one shaft. I do approve, however, of a dynamo on each end of the shaft, *i.e.*, at each side of the engine, which is a very different thing. Dynamos of the first class are only to be tolerated under special conditions, and I would not be surprised to find them ruled out of court by competent engineers whenever these conditions are not present.

Mr. Esson

I think that I am right in saying that the active belt of the machine becomes more active as the speed is reduced, because the induction in the belt can then be put up and the output depends on this; but Mr. Mavor is quite correct in pointing out that he never stated that the coefficient I use had the same value in different machines. Perhaps we regard the use of coefficients from a different standpoint. In my view their chief uses are two: first to determine quickly the carcase dimensions of a new machine so that we can get out an estimate of its cost, secondly to see if we are getting from a machine of given carcase dimensions the best it can do. Now, any constant which embraces a term depending upon the depth of the slots is, to my mind, useless for these purposes, as this depth has nothing to do with the weight of the machine upon which its cost depends. Mr. Ledward's remarks I do not understand. He seems to have discovered a mare's nest, and fails to understand that the several values upon which the output of machines depend can be massed together in one term which, in conjunction with the carcase dimensions of the machine and its speed, serves all purposes.

Coming to alternating-current work, Professor Silvanus Thompson points out that in modern alternators the pole-pitch is practically uniform. That, of course, cannot be otherwise if the frequency in the several cases is the same and the peripheral speed is also similar. It will be seen from the figures for alternators in Mr. Scott's Table VII. that the peripheral speed generally lies between 5,000 and 6,000 feet per minute, the former at 50 frequency corresponding to a pole-pitch of 10 inches and the latter to 12 inches. Professor Thompson knows very well, of course, that the voltage, efficiency, drop, and specific utilisation of material have nothing to do with this point, it depends entirely on the peripheral velocity and frequency; at the same time, like Professor Thompson and Mr. Clark, I do not remember uniformity of pitch having been referred to in print before. But when Professor Thompson endeavours to base on this mere accident a general principle of design, it is time to call a halt, for a moment's reflection will show him that his proposition as to circumference of working face is untenable. Imagine a machine of 100 frequency with a surface velocity of 10,000 feet per minute! And yet we are called upon sometimes for machines of 100 frequency.

Mr. Clark remarks that I am very conservative in fixing 6,000 feet per minute as the maximum advisable limit of magnet velocity. I may be conservative, but I would not say "very," for in modern machines it is rarely that this velocity is exceeded. I have myself gone up to 7,920 feet on special occasions; the machines are running quite satisfactorily, and up to the present nothing has burst; at the same time I think, as mentioned in the paper, that 6,000 feet is quite high enough, and reference to Mr. Scott's Table VII. will show that in no case is this exceeded in the alternators he cites.

Mr. Eborall referred to the better qualities of high-speed alternators as compared with those of low speed, but there is one point he did not refer to, and that is, that on account of each element of the machine—consisting of a set of armature coils and pole—giving in the high-speed

generator a greater output it is more efficient. In the low-speed machine we have a great number of elements each giving a small output, in the high-speed machine a small number of elements each giving a comparatively large output—hence the greater efficiency of the high-speed machine. Mr. Esson.

I quite agree with Mr. Eborall as to forced draught for transformers in preference to oil, and I entirely disagree with Mr. Ledward as to the shell type being either cheaper or more efficient. But as regards the Heyland motor, Mr. Eborall knows as well as I that in non-synchronous machinery the commutator constitutes the one element of impurity which it is our sole aim and endeavour to avoid. From this point of view, therefore, the Heyland motor is not a purely inductive machine, hence my describing it so in the paper. With reference to the drop in alternators, I did not say that 2½ per cent. was attained in practice, but that trade representations were made to this effect. Mr. Eborall will know, of course, that there is a difference—sometimes. To the statement that English machines were far too heavy until recently, I must still adhere. No doubt 2½ per cent. drop would be better than 4 per cent., other things being equal; but other things would not be equal, inasmuch as the cost for the small drop would be prohibitive, and, as Mr. Eborall points out, the parallel running would be bad. Accordingly, after showing that the small drop is desirable, my critic goes on to show it is unnecessary; and as that is just the conclusion arrived at in the paper, the matter may be left there. One other point mentioned by Mr. Eborall has reference to two-phase and three-phase motors, and he states that the former are inferior in output, power-factor, and efficiency to the latter. I think if he looks into this matter he will find that the three-phase motor requires more copper than the two-phase, which would probably account for the difference.

With Mr. Sparks' observations on the subject of "Conversion" I agree generally, but it was not my intention on the occasion of the discussion on Mr. Eborall's paper to indicate difficulties in controlling the pressure when non-synchronous motors were employed. I merely pointed out that certain precautions had to be adopted in controlling the pressure, which is quite a different thing. When these precautions are taken no difficulty whatever is experienced, and for every kind of machinery the regulating gear suitable to its use must be installed if satisfactory results are to be attained. With these remarks I thank you all for receiving my paper so kindly.

Mr. E. Kilburn Scott, in reply: Referring to the conditions necessary for sparkless commutation, Prof. Carus-Wilson shows that the method I give of comparing ampere-turns of air-gap with cross ampere-turns, as well as the reactance voltage method of American designers, both fail to meet the case. Even with these incorrect methods, however, the dynamo has developed into a fairly satisfactory machine, helped, no doubt, by the use of carbon brushes, saturation of iron round the air-gap, and in traction generators by the *over-compounding*. At the same time it would be most interesting to have the results of a series of tests such as Prof. Carus-Wilson has hinted at. Mr. Scott.

Mr. Eborall objects to the item in my standard specification of

Mr. Scott.

alternators, dealing with the number of slots. In mentioning two slots. I was thinking of average-sized machines. For very large outputs, more slots would of course become *economically* possible from the manufacturing point of view.

Regarding the comparison of two- and three-phase machines, I must confess to having considered the matter in a very general sense, namely, that the three-phase armature has all its slots occupied, and the two-phase only two-thirds of the slots. I know that in practice this relation is not quite followed, and that questions of cooling surface, etc., come in to limit the output.

Mr. J. H. Barker is wrong about the Metropolitan Railway turbo-alternators, for I saw them recently under construction at the Trafford Park Works.

Late delivery of dynamo cast steel certainly does handicap many English firms. On the Continent there is not the same difficulty, because several concerns make a speciality of such steel. Messrs. P. R. Jackson & Co. and the Westinghouse Company, who make their own steel, have a big pull, as they not only get immediate delivery, but the steel is to standard quality.

Single-core plates are thicker than segments, but as the latter have to be arranged in pairs, metal to metal to break joint, there is not much in it.

Mr. C. C. Hawkins rightly points out that the maximum output obtainable from any given carcase and quantity of copper and iron, is the information most desired. Unfortunately designers generally prefer to keep such data to themselves. Where firms design very closely to the specified requirements, it is a good deal due to their employing standard carcases and thoroughly testing every new size. In this country I am afraid the testing department is not in close enough touch with the designing and drawing offices, and I have also noticed a laxity in entering up the particulars of *such few tests* as are made.

Armature conductors with a single bend take up more room, but this becomes of less importance the greater the number of poles. I certainly think that anything which does away with bands and wedges to hold the conductors in position is a step in the right direction.

Regarding carbon brushes, I object to loose sliding carbon blocks for large dynamos because of their loud chattering noise.

Vacuum drying is principally employed for drying out the coils, but after they are assembled the completed armature may also be treated. I do not think there is any more difficulty in removing the last traces of moisture than with ordinary baking.

Prof. S. P. Thompson's elaboration of the output equation is instructive, and his further remarks on equalising rings will help to draw attention to the necessity of making provision against inequality of air-gap and magnetic value of the poles. I note that the Westinghouse Company guarantee that by their method the armature may be as much as $\frac{1}{16}$ inch out of centre without detriment.

I had not heard of water-glass as an insulator of core discs; its refractory character should give it additional value.

That the pole-pitch of alternators averages $9\frac{3}{4}$ inches for a

frequency of 50 ∿ is a useful fact to know. Curiously enough the same peculiarity is referred to in Mr. E. V. Clark's remarks. Mr. Scott.

Mr. V. A. Fynn thinks it unnecessary to cast the yokes in a solid ring, and if one could be sure that the two halves were run from the same ladle of metal it would not matter. When two halves are cast together the quality *must* be the same. If the armature end plates have fingers cast on to support the teeth, then the core discs need not be reduced in diameter at the corners. Unless the teeth are fairly large, however, such fingers may snap off.

The fact that the figures I put forward differ so much from those found useful by Mr. Fynn, shows the necessity of ventilating this question of size for a given output. I believe greater outputs could be obtained per pound of iron and copper than is at present the case with many English machines.

Prof. David Robertson's remarks form quite a treatise on armature windings, and I am pleased to have his corrections and criticisms. The windings *actually* employed in the workshop are few, but it is necessary to have some law or equation governing all types such as Prof. Robertson has given. His suggestion of machines having two commutators is interesting, but too expensive. As pointed out in Fig. 17, there has been a slip in making the block.

Mr. H. V. Bowen refers to the Arnold series parallel winding. There is no doubt that for all ordinary-sized machines this winding has been very successful. I have not, however, had an opportunity of observing its effect on such an extreme case as a 30-pole dynamo at 90 revolutions per minute.

Possibly the two 6-pole generators mentioned were overrated in output. Much overrating goes on, and is not confined to Continental makers. Some rules such as the American Institution of Electrical Engineers have adopted would go far to reduce the practice.

I am glad Mr. Bowen has given the additional data of his three multipolar dynamos; it is a much needed example to other designers in this country.

In conclusion I have to thank all those who have contributed to the discussion for their critical and interesting remarks. Regarding features which I may seem to have put forward as novel, I might just say that the paper was written two and a half years ago. In giving the tabulated data and dimensions, etc., I wished to put on record certain particulars which I thought might be useful to others. I think they may be taken as fairly representative.

The President announced that the scrutineers reported the following candidates to have been duly elected:—

Members.

Wilson S. Carr. | William Herbert Donner,
Robert Hood Haggie.

Associate Members.

Hugh Bourne.
George Alfred Brade.
Lawford Stanley Foster Grant.
Walter Charles Heavysege.
Henry Norman Holland.
Arthur C. Johnson.
Sidney Mellor.
William Duke Palmer.
Charles Edmund Pecsenik.
Robert Edward Robson.
Sydney Aston Mersey Rose.
George Ernest Sanders.
John Edward Tapper.
William Izett Walker.
Charles Stevens Ward.
John Henry Watkins.
Ettrick Lovell Webb.

Associates.

Rupert Stanley Allen.
Fountaine M. Burrell.
John Maldin Harvard.
John Henry Hopton.
William Day Kirkpatrick.
John Spencer.
Norman Wells.

Students.

Percy Everett Banting.
Stephen Donald Barnwell.
Edgcumbe R. Brighton.
F. H. Brun.
Albert Dixon Forster.
William James Freeman-Horn.
Bertram Barrett Grace.
George Cuthbert Hatton.
Herbert Hayhurst.
Franklin Thomas Homan.
Edward W. Jackson.
Richard Pelham Jephson.
Thomas Frederick Lee.
Stanley L. Burnett Lines.
Charles J. Cuthbert Moon.
R. C. Plowman.
Herbert Sidney Plymen.
Harry Stansfeld Porter.
Rowland Rees.
John Duncan Reid.
Clive Smith.
Frank Fawcett Smith
Wilfred Wallis Soutter.
Roland Francis Thomas.
John Turnbull Tiplady.
Laurence R. Wallace.

No. of Certificate 18,393. | N. L. 17,801.

THE COMPANIES' ACTS 1862 TO 1900.

[COPY.]

SPECIAL RESOLUTION

(Pursuant to the Companies' Act, 1862, Sections 50 and 51)

OF

The Institution of Electrical Engineers.

Passed February 26, 1903, *Confirmed March* 17, 1903.

At a SPECIAL GENERAL MEETING OF THE MEMBERS ONLY of the above-named Institution, duly convened, and held at the Institution of Civil Engineers, Great George Street, in the City of Westminster, on the twenty-sixth day of February, 1903, the following SPECIAL RESOLUTION was duly passed ; and at a subsequent SPECIAL GENERAL MEETING of the Members only of the said Institution, also duly convened and held at the Westminster Palace Hotel, Victoria Street, in the City of Westminster, on the seventeenth day of March, 1903, the following SPECIAL RESOLUTION was duly confirmed :—

RESOLUTION.

"That the Regulations contained in the Articles of Association of the Institution be altered in the following manner, that is to say :—

1. ARTICLE 38. By adding the following words at the end of the existing Article :—

> "In case any individual shall be adjudicated bankrupt, or convicted of felony, the Council may, without any such proposal or steps as aforesaid, decide that his name shall be removed from the Register of the Institution, and the Secretary shall communicate such decision to the individual according to the Form EE in the schedule."

2. ARTICLE 41. By adding the following words at the end of the existing Article :—

> "And the President shall be chosen from the Vice-Presidents and those who have been Vice-Presidents of the Institution, or predecessors of the Institution, and the Vice-Presidents shall be chosen from those who are, or have been, Members of the Council of the Institution, or predecessors of the Institution."

3. ARTICLE 42. By striking out the expression "one Vice-President" wherever it occurs in the Article, and substituting in each case the expression "two Vice-Presidents."
4. ARTICLE 50. By striking out the words "Immediate Past President and the four senior," and substituting the words "five junior."
5. ARTICLE 54. By inserting the words "and Associate Members" after the words "Special General Meetings of Members."
6. ARTICLE 56. By inserting the words "and Associate Members" after the words "1st Special General Meetings of Members."

7. ARTICLE 62. By adding the words "and Associate Members" after the words "vested only in a Special General Meeting of Members."

8. SCHEDULE FORM B. By adding the expression "aged " after the expression "A. B. "

9. SCHEDULE. By inserting after the Form E the following Form :—

"EE.

"The Institution of Electrical Engineers.

"Sir,

"It is my duty to inform you that on the day of the Council decided, according to Article 38, that you should be declared to be no longer belonging to the Institution.

"I am, Sir, etc."

10. SCHEDULE. By cancelling the Form G, and substituting therefor the following :—

"G.

"The Institution of Electrical Engineers.

"I, the undersigned, having been elected a of the Institution of Electrical Engineers, do hereby request to be registered as such and agree that I will be governed by the Rules, Regulations, and Articles of the said Institution as they now are, or as they may hereafter be altered ; and that I will advance the objects of the Institution as far as shall be in my power ; provided that, whenever I shall signify in writing to the Secretary that I am desirous of withdrawing from the Institution I shall (after the payment of any arrears which may be due by me at that period) be free from this obligation.

"Witness my hand, this day of ."

WALTER G. McMILLAN,
Secretary.

GLASGOW LOCAL SECTION.

THE DESIGN OF CONTINUOUS-CURRENT DYNAMOS.

By HENRY A. MAVOR, Chairman of the Section.

(*Paper read at Meeting of Section, Nov.* 11, 1902.)

Following up the paper on this subject read by the present author at the International Engineering Congress, Glasgow, 1901, there are some points to which he proposes to give further elucidation. As in the case of the former paper, it is not proposed to enunciate any new theories, or to discuss the bases of dynamo design. The present investigation has to do rather with the application to practical design of the results of the calculations and experiments of others. The generally accepted constants and formulæ may be by this means subjected to such criticism as to lead to modification of generally accepted views, and therefore such an investigation is not without its uses.

Referring back to the Congress paper, the author there suggested that the essential part of the dynamo is the region occupied by the armature conductors in the magnetic field, and suggested the name "Active Belt" for this region, which is bounded by the peripheral surface of the armature, the surface of the core at the bottom of the slots, and the ends of the core. He pointed out that an examination of the dynamo in terms of the energy generated in this active belt shows that machines of widely varying size, output, and speed, give a remarkably constant value in watts generated per cubic centimetre of active belt at unit velocity in unit field.

In an interesting paper read before the British Association in Belfast this year by Professor Silvanus Thompson, the professor gives the results of calculations on a large number of machines considered from this point of view, and confirms the value given in the Congress paper referred to. This value is often exceeded, but the statement originally made that 5 ergs per second per cubic centimetre at unit velocity in unit field may be counted upon as a safe load, is fully confirmed. The application of this method of study to machines of smaller sizes has shown that this value must be subjected to considerable modification, the reason being that in the smaller machines the losses in the armature are relatively more important than in the larger sizes.

On machines of 24 inches diameter and upwards it appears that the output may safely be given in watts per revolution, that is to say, that a given carcase will give an output directly, or nearly directly, proportional to the speed of rotation of the armature. In modern designs of large machines it is not difficult to determine this output, both with regard to the commutating conditions and to the temperature of the armature.

The design of the smaller machines, for which the market is very rapidly increasing, is not less worthy of close attention, and it would

appear, judging from the machines now on the market, that this part of the subject has not yet received the attention which it deserves. A very interesting series of articles at present appearing in the journal *Traction and Transmission*, by Mr. Henry M. Hobart, is dealing somewhat fully with this subject, and should be read by all interested in dynamo design.

In this connection it is interesting to note as a forecast of the probable development in this country, that in America the year's census of work, according to the American *Electrical World*, is 9,182 continuous-current machines of 428,601 H.P., giving an average of only 35 k.w. per machine for the year 1900.

Confining, as before, our attention to the armature, the points requiring consideration in the design of the machine arise primarily from the commutating conditions, and from the limit of temperature rise imposed. The commutating conditions on small machines can be fairly safely dealt with on the lines indicated in the Congress paper, and it will be found that this part of the question is much more easily solved than the other. The temperature rise in the armature is taken to be due to the following expenditures of energy on the material of the armature :—

(1) Hysteresis in the core.
(2) Eddy currents in the core.
(3) Hysteresis in the teeth.
(4) Eddy currents in the teeth.
(5) Eddy currents in the winding.
(6) C^2R losses in the winding.

These are the losses which may be expressed in watts, to be deducted from the effective watts of the machine.

The subject of hysteresis and eddy currents has been discussed with great fulness in various treatises on magnetism and on dynamo design, and it is not proposed here to enter into any discussion on these subjects, but to assume relations between those losses and the induction, periodicity, and weight. It is quite certain that the constants deduced from the study of these phenomena in the past must be subjected to some considerable modification, and the story is not yet told of all that takes place in a piece of iron under changing magnetisation and in a copper conductor in a changing magnetic field, but the constants now in general use have proved sufficiently near the truth to warrant their being used for our present purpose, and we may therefore follow to a logical conclusion the assumptions involved in those constants, reserving to ourselves the right to retrace our steps and amend our constants when they prove inconsistent with the results of experience. We are just as much warranted in doing this as we are in accepting the tests of tensile strength of steel and cast iron, and to all appearance the electrical data are even more reliable than the physical data to which we have referred.

It is customary to treat hysteresis and eddy currents in the core, and hysteresis in the teeth as being proportional to the periodicity, or the rate of change of magnetisation in that core, that is to say, to the speed. he eddy currents in the winding are usually assumed to be negligible

in machines in which the winding is embedded in slots and tunnels, and to be also of comparatively small importance on smooth-cored machines where the conductors are well laminated.

These losses appear as heat, producing a rise of temperature in the armature. The cooling effect of the circulating air round the moving armature tends to dissipate the heat, and a point is found when the heat production in the armature is balanced by the radiation from it, and the temperature becomes approximately constant. It is customary to specify this constant temperature at something between 70 deg. and 90 deg. Fahr. above the temperature of the surrounding air.

On small machines this is an exceedingly uncertain standard, because it is difficult to ascertain what is the temperature of the armature. It is difficult even to ascertain what is the temperature of the surrounding air. There is a further difficulty that a very insignificant variation in the condition or distribution of the material in a small machine very materially modifies the temperature rise. As, however, no more satisfactory standard of comparison has been generally adopted, we shall also assume for the purpose of the argument that it is practicable to forecast the temperature rise of the machine, and to measure it when it occurs. For practical purposes, speaking generally there is no very great difficulty in doing so. The exceptions which frequently arise are usually due to ascertainable abnormalities.

Assuming for the present that the proper constants have been ascertained for determining each of the losses, we may symbolise them by—

$A_{I}\, n =$ Hysteresis and eddies in the core in watts.
$A_{II}\, n =$ Hysteresis in the teeth in watts.
$A_{III}\, n^2 =$ Eddies in the teeth in watts.
$A_{IIII} =$ Watts lost in the winding.

The radiation of heat from the armature is taken as proportional to the square root of the speed.

The constants are determined for any given rise of temperature by experiment. The expression for the total lost watts radiated by the armature takes the form—

$$A_{V} \quad \sqrt{n},$$

and the copper loss is ascertained by deducting the iron losses from the value $A_{V} \sqrt{n}$.

Thus $A_{V} \sqrt{n} - A_{I}\, n - A_{II}\, n - A_{III}\, n^2 = A_{IIII}$

That the text of the paper be not unduly defaced by formulæ, they are relegated to an Appendix which gives constants and formulæ—(1) For the determination of core and tooth losses. (2) Radiation from the surface of the core. (3) The watts generated by the machine, its output, and efficiency.

The total watts generated in the winding of a dynamo, or absorbed in the winding of a motor armature, are directly proportional to the square root of the watts lost in the winding, the square root of total

cross-sectional area of the copper, the volume of the core, the induction in the air space, and to the rate of revolution and inversely proportional to the square root of the length of each turn of the winding.

Thus $$W = \frac{\sqrt{A_{\prime\prime\prime\prime}} \times \sqrt{Q\, S_{v}} \times \pi DL\, B_{av} \times 10^{-5} \times n}{\sqrt{2L + \frac{D\, 7{\cdot}44}{P}}}$$

See Appendix III.

This formula for total watts symbolises the fact that the total output of the armature varies as the square root of the loss in the winding and directly as the speed. Now, if the loss in the winding be relatively small, the output will, for practical purposes, vary directly with the speed. This is the case in large machines. In small armatures, on the other hand, the winding loss is relatively large, and it is worth while to look for the conditions which give maximum output.

This can with a little labour be done for any machine by a simple graphic method.

Plotting the values of $\sqrt{n}$, n and n^2, multiplied by the relative constants, to scale we get a diagram for any armature giving the value of $A_{\prime\prime\prime\prime}$ (Fig. 1).

Again plotting values of W and n we get a diagram of the form shown in Fig. 2.

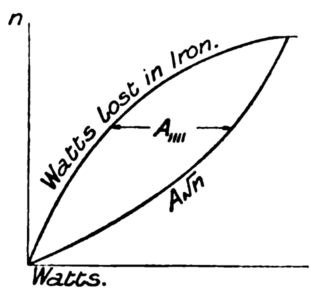


FIG. 1.

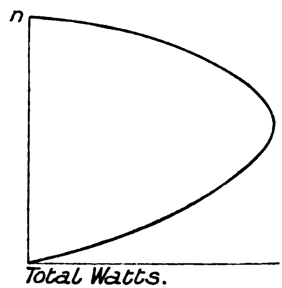


FIG. 2.

The form of this curve is interesting. It shows that there is for every machine a maximum possible output for a given rise of temperature, and that this maximum is at a definite speed of rotation. The position of this curve and of its maximum may be varied by several means.

For low speed the total watts and the efficiency are greater with a deep slot and high inductions.

For high speed the total watts and the efficiency are greater with a shallow slot and low inductions.

The ratio between the iron and the copper can be adjusted to suit the conditions of work to which the motor is likely to be subjected. If, for example, it has to run constantly with a varying load on outside

supply paid for by meter, it is evident that the iron losses should be kept low and the copper losses high; whereas if the machine is to run at full load, it should be designed to give the output under the most favourable conditions of combined iron and copper losses. Attention to this point results in a very considerable saving in cost of working.

A reference to the formulæ in the Appendix will show how the values of these losses have been determined. The losses in the core are seen to depend upon its weight, the core induction, and the periodicity of magnetic reversal. See Appendix I.

It is convenient to find expressions deriving the core induction from the induction in the air space, and this is contained in a formula given in Appendix I.

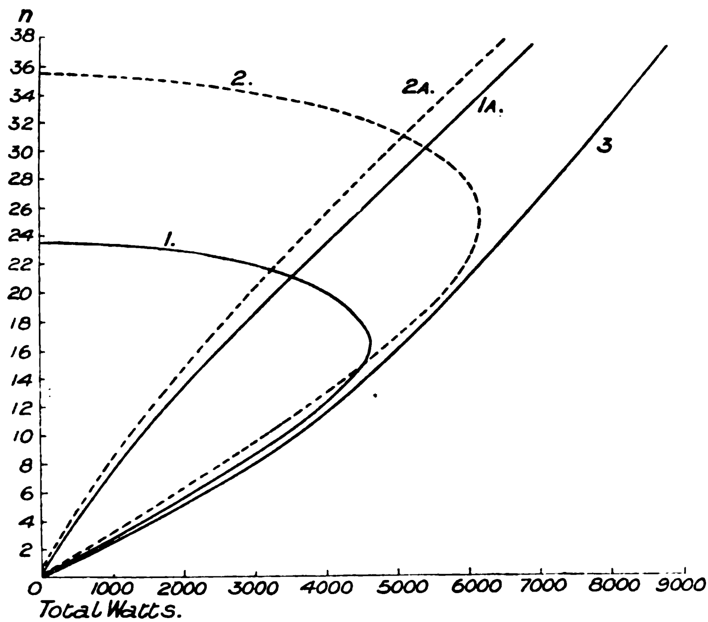


Fig. 3.

A high value of the induction keeps down the quantity of material in the active belt, the number of turns of wire required, and the reactance voltage. On the other hand, the induction in the air space is limited by the necessity for mechanical clearance and by the size of the carcase. The author has not gone into the investigation of the highest permissible value of the induction in the air space. This maximum will be found to depend with any given form of magnet on the relation between the length of the path through the magnet and the space available for wire.

It is now almost universal to demand a fixed brush position for all loads, and therefore it is of the highest importance that the values of

the induction in the air space and teeth should be kept as high as practicable.

The range of speed variation by shunt regulation depends on the reduction of the field strength, so that it is advantageous on this ground also to have the initial strength as high as possible.

It will be seen that the value of the core loss is not susceptible of any very great variation, that a reduction in the quantity of material with consequent increase in the induction does not materially affect the loss in the core. We therefore turn to A_{II} and A_{III} as the quantities susceptible of the most effective change.

A_{II} and A_{III} are seen to depend upon the weight of the teeth. Here again it is convenient to derive this weight directly from the slot depth, and a formula has been arranged and given in Appendix I., deriving the dimensions of tooth and slot from the slot depth, the induction in the air space and the maximum induction in the teeth. The factor which is susceptible of the most effective variation is the slot depth, and diagrams showing the effect of the variation of the slot depth take the form shown in Fig. 3, which is worked out for a machine of ten inches diameter.

The value of the induction in the teeth, though susceptible of considerable variation, cannot be reduced so as to materially affect the result. Considerations of commutation call for a high value of the tooth induction as well as of the induction in the air space, so as to provide a "stiff" field and to throttle or minimise cross induction and consequent shifting of the diameter of commutation with change of load.

The limit to the tooth induction appears to be fixed by the risk of the leakage field into the slot, causing eddy currents in the conductor. The values of the induction in the air space which appear to be adopted in current practice, and as indicated in the paper by Professor Silvanus Thompson already referred to, appear to be not very far from the value chosen in the Congress paper, viz., about 6,000 to 8,500 lines per centimetre.

The value of the tooth induction commonly adopted is a maximum of 20,000 to 22,000 lines per centimetre.

Speaking generally, the changes which can be made have the following effect:—

Increase of core induction, slot depth, air space induction, and tooth induction all have the same effect upon the output curve of the machine as increase in speed, and increase in slot depth produces by far the most conspicuous change.

The iron losses decreasing with decrease in slot depth, a point is reached when the slot becomes too shallow to hold the wire, and a limit is reached in this direction.

If the wire be outside the slot, the risk of eddy current loss must be taken into account.

Turning now to the value $A\sqrt{n}$. The radiation factor is susceptible of some variation. The demand for enclosed motors—which we may say, in passing, does not seem to have any good theoretical justification, but like so many demands which have become common,

and which have been accepted by the designers of machines without sufficient consideration or resistance to outside influence, appears to be entirely injurious—this requirement of enclosure of the motor, which prevents circulation of air, and thus prevents the armature from getting rid of its heat to the moving air, restricts the output of the machine quite unnecessarily. Under certain circumstances it is necessary to protect the motor from moisture, but the most injurious kind of dust which can lodge on an armature is the dust from the commutator and brushes. A good hard commutator and high quality of carbon brush make very little dust, but a certain amount of wear on the carbon brush is unavoidable, and the carbon dust is a conductor, whereas most of the dust floating in the atmosphere consists of oxides, silicates, and other non-conducting matter.

Artificial methods of ventilating the motor shell are possible, and in cases where the motor must be protected from damp may be found useful, but the best way of procuring a circulation of air is, where it is possible, to expose the motor freely to the atmosphere. Ventilation of the cores of small machines is an expensive, and on very small machines an impracticable, expedient.

Turning now to the question of efficiency—

This may be considered from the points of view of use of material, and of conversion of energy.

Taking the use of material first.

If we insert the value now given for W, the total watts of the machine, in the value of K (see Appendix III.), we get—

$$K = \text{ergs per second per cubic centimetre per second} \times 10^7$$
$$= \frac{\sqrt{A_{111}\, Q\, S_v} \times 10^{-5}}{\pi\, d\, s \times \sqrt{2L + \frac{D\, 7{\cdot}44}{P}}},$$

which brings out very clearly the importance of the cross-sectional area of the copper on the machine.

$Q\,S_v$ is this factor.

The energy per cubic centimetre of the active belt is proportional to the square root of this value, and inversely proportional to the square root of the length of each turn and to the depth of the slot.

The author has for some time been using the method of consideration first published, so far as he is aware, by Mr. Henry M. Hobart in his paper in *Traction and Transmission* in October, 1902, in which he lays great stress upon the importance of a high value for the cross-sectional area of copper in the active belt ($Q\,S_v$).

While admitting to the full the truth of Mr. Hobart's remarks on this point, it must not be forgotten that the insulation of armature conductors has to be considered as a question of mechanical clearance and protection as well as of specific insulation, so that it is conceivable that a high value of Q would result in greater risk of breakdown from the armature conductors coming into contact with one another in handling. This is a point which can only be settled by experience, and the arguments used in favour of multiple coverings on cables apply with still greater force to armatures, *i.e.*, that a covering in

many layers of a lower specific insulation is better than a covering of one layer of higher specific insulation. This accounts for the practice of covering armature conductors with several layers of tape, and, in addition, insulating the slot itself by means of paper, or binding paper to the conductors themselves. The use of a comparatively thick layer of paper is much more effective and safer than of a thinner layer of mica, which, though of a much higher insulating property is much more liable to mechanical damage.

The efficiency of conversion of energy is the ratio between—

$$\frac{\text{Total watts generated less watts lost in machine}}{\text{Total watts generated plus watts lost in iron}} = \frac{W - A_{\text{IIII}}}{W + A_{\text{V}}\sqrt{n} - A_{\text{IIII}}}$$

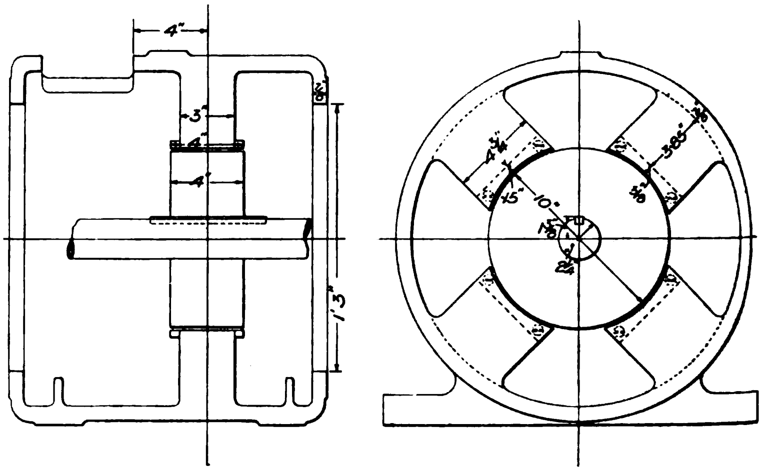


FIG. 4.

Here again the importance of keeping down the iron loss is clearly brought out, and the diagrams show the great importance of this factor in a small machine.

Figs. 1, 2, and 3 summarise the argument of this paper. They contain five curves, and have reference to a machine the carcase of which is shown in longitudinal and in cross section in Fig. 4. Curve No. 1 (Fig. 3) represents the total watts generated in the armature, which is 25·4 centimetres in diameter, 10·16 centimetres long, with a slot depth of about 2·38 centimetres, and was run at a speed of 1,000 revs. per minute, giving an output of 4,600 watts, with a temperature rise of about 70° Fahr. above the temperature of the surrounding air.

Curve No. 2 represents the total watts generated by a similar armature with a slot 1·6 centimetres deep, which was run at the same speed and gave approximately the same output.

Curves Nos. 1A and 2A represent the calculated outputs of two armatures, respectively with the same windings as 1 and 2 but with no slots, *i.e.*, smooth cores with different depths of winding.

Curve No. 3 is the approximate envelope of all possible curves of output for this carcase. This curve may be slightly varied by variation in the inductions, but within practical limits it is not subject to much variation, and shows the maximum output obtainable from the carcase at all speeds.

The magnet winding and air space induction are the same in all the cases.

A study of this diagram will throw considerable light on the problem of estimating the possible output from any carcase, and also upon the probable effect of speed of rotation on the output of any given machine carcase. It will be evident that as the iron losses become less important, as they do in the larger sizes, the envelope will tend to become fuller in form, and as the speed of the larger sizes of machines is limited by the strength of the material, the rate of rotation is reduced, the upper part of the curve becomes of less importance, and the lower part of the curve approaches more and more nearly to the straight line, which is consistent with the experience that on the larger sizes the watts generated are nearly directly proportional to the speed of rotation.

SYMBOLS USED IN APPENDICES.

B_a = Induction in air space in c.g.s. lines per centimetre.
B_c = Induction in core, lines per square centimetre.
B_t = Induction in teeth in c.g.s. lines per centimetre.
C = Total current in amperes.
E = Total E.M.F. of armature in volts.

G = Sections in commutator.
d = Diameter of core measured to the middle of the active belt, in centimetres.
d_1 = Internal diameter of core discs in centimetres.
d_2 = Diameter of core to bottom of teeth, in centimetres.
D = Diameter of core overall, in centimetres.
L = Length of core in centimetres.
m = Armature turns per section of commutator.
n = Revolutions per second.
p = Paths through armature.
P = Number of poles in the machine.
$Q = \frac{\text{Copper area in slot}}{\text{Area of slot}}$.
S = Depth of slot in centimetres.
S_v = Area in centimetres of 1 slot × number of slots.
$x = \frac{\text{Pole surface} \times \text{P}}{\pi \text{D L}}$.
y = Ratio of $\frac{\text{Iron in core}}{\text{total cubic content of core}}$.

APPENDIX I.

Formulæ and constants for determining core and tooth losses :—

Hysteresis and Eddies in the Core.

$A_1 n$ = weight of core discs in lbs. × $B_c^{1\cdot6}$ × periodicity × $3\cdot25 \times 10^{-8}$.

Weight of core discs $= \cdot0168\, y \frac{\pi}{4} (d_2^2 - d_1^2)$ L.

Weight of one cubic c.m. of iron = ·0168 lbs.

$$B_c = \frac{B_a x \pi D L}{P y (d_2 - d_1) L}.$$

$$\text{Periodicity} = \frac{P n}{2}.$$

HYSTERESIS IN TEETH.

$A_{II}\, n$ = weight of teeth $\times B_t^{1\cdot6} \times$ periodicity $\times 1\cdot85 \times 10^{-8}$.

EDDIES IN TEETH.

$A_{III}\, n$ = weight of teeth $\times B_t^2 \times \left(\frac{P n}{2}\right)^2 \times 3\cdot84 \times 10^{-12}$.

Weight of teeth is derived from—

Belt volume $= \pi \left(\frac{D}{2}\right)^2 - \pi \left(\frac{D - 2 S}{2}\right)^2 = \pi S (D - S)$.

Total width of teeth at bottom $= \frac{B_a x \pi D}{B_t y x} = \frac{\pi D B_a}{B_t y}$.

Total width of slots $= \pi \left(D - 2 s - \frac{B_a D}{B_t y}\right)$.

Volume of slots $= S_v\, L = L \pi s \left(D - 2 s - \frac{B_a D}{B_t y}\right)$.

Vol. of teeth $= L \left[\pi s (D - S) - \left(D - 2 s - \frac{B_a D}{B_t y}\right)\right] = L \pi s \left(S + \frac{B_a D}{B_t y}\right)$.

Weight of teeth $= \cdot0168\, y L \pi s \left(S + \frac{B_a D}{B_t y}\right)$.

APPENDIX II.

These constants are believed to be reasonably accurate, but they have to be carefully checked by actual results for various types of carcase.

Formulæ and constants for determining radiation from the surface of the core only for a rise of 70° Fahrenheit, above an atmospheric temperature of 70° Fahrenheit :—

Partially enclosed Armatures, without ventilating spaces.

$A_v \sqrt{n}$ = watts radiated from core surface $= \pi D L \times \cdot0073 \times \sqrt{\pi D n}$.

Open Machines, Armatures, with ventilating spaces.

$A_v \sqrt{n} = \pi D L \times \cdot0152 \times \sqrt{\pi D n}$.

Open Machines, Armatures, without ventilating spaces.

$A_v \sqrt{n} = \pi D L \times \cdot01 \times \sqrt{\pi D n}$.

Totally enclosed Machines.

$A_v \sqrt{n} = \pi D L \times \cdot0073 \times \sqrt{\pi D n}$ for 90° rise.

Formulæ and constants for determining radiation from the whole surface of core and end winding for a rise of 70° Fahrenheit, above an atmospheric temperature of 70° Fahrenheit :—

Partially enclosed Armatures without ventilating spaces.

$$A_r \sqrt{n} = \pi D \left(L + \frac{2 D}{P}\right) \times \cdot 00565 \sqrt{\pi D n}.$$

Open Machines, Armatures, with ventilating spaces.

$$A_r \sqrt{n} = \pi D \left(L + \frac{2 D}{P}\right) \times \cdot 01 \sqrt{\pi D n}.$$

Open Machines, Armatures, without ventilating spaces.

$$A_r \sqrt{n} = \pi D \left(L + \frac{2 D}{P}\right) \times \cdot 008 \sqrt{\pi D n}.$$

Totally enclosed Machines.

$$A_r \sqrt{n} = \pi D \left(L + \frac{2 D}{P}\right) \times \cdot 00565 \sqrt{\pi D n}, \text{ for } 90^\circ \text{ rise.}$$

APPENDIX III.

Formulæ and constants for determining winding data :—

$$\text{Length of end winding} = \frac{4 D}{P} \sqrt{1 + \frac{\pi^2}{4}} = \frac{D\, 7{\cdot}44}{P}.$$

$$\text{Length of one turn complete} = 2 L + \frac{D\, 7{\cdot}44}{P}.$$

$$\text{Resistance of one turn} = \left(2 L + \frac{D\, 7{\cdot}44}{P}\right) \frac{2 m G}{Q S_v} \times \cdot 2 \times 10^{-5}.$$

$$\frac{\text{Copper area}}{\text{Slot area}} = Q, \text{ area of each conductor} = \frac{Q S_v}{2 m G}.$$

Specific resistance of copper at 130° F taken at $\cdot 2 \times 10^{-5}$.

$$\text{Weight of copper on armature} = \frac{Q S_v}{2} \left(2 L + \frac{D\, 7{\cdot}44}{P}\right) \cdot 0194.$$

$$* A_{IIII} = \left.\begin{matrix}\text{watts lost in} \\ \text{winding}\end{matrix}\right\} = \left(\frac{C}{p}\right)^2 \left(2 L + \frac{D\, 7{\cdot}44}{P}\right) \frac{2 m G}{Q S_v} \times \cdot 2 \times 10^{-5} \times m G.$$

$$\therefore \frac{G m C}{p} = \frac{\sqrt{A_{IIII}} \times \sqrt{Q S_v} \times 500}{\sqrt{2 L + \dfrac{D\, 7{\cdot}44}{P}}},$$

$$\text{and } E C = \frac{G m C}{p} \times \pi D L \times B_a x \times 10^{-8} \times 2 \times n,$$

* Where the output is calculated from the radiation from core only, substitute 2 L for $2 L + \frac{D\, 7{\cdot}44}{P}$ in value of A_{IIII} for watts lost in slot winding only.

$$\therefore \; EC = \frac{\sqrt{A_{1111}} \times \sqrt{Q\,S_v} \times \pi D L B_a x \times 10^{-5} \times n}{\sqrt{2L + \frac{D\,7.44}{P}}} = W.$$

$$K = \frac{W}{\pi D L s \times \pi d n \times B_a x} = \frac{\sqrt{A_{1111}} \times \sqrt{Q s v} \times 10^{-5}}{\pi d s \times \sqrt{2 L \times \frac{D\,7.44}{P}}}.$$

Mr. Field.

Mr. M. B. FIELD: During the past sessions we have had papers on all sorts of subjects, but I think none on dynamo design, so that this paper, written as it is by an experienced manufacturer of dynamos, comes in very opportunely. To my mind the most important fact that Mr. Mavor brings out is that, given a certain carcase, comprising field magnet and armature, the latter without a winding, there will be one particular speed at which the output of the dynamo or motor is a maximum, provided we are limited to a definite temperature rise. I understand Mr. Mavor to say that there are standard motors on the market to-day, built by standard makers, which are not adjusted to run at this particular speed of maximum output, although this speed may be quite a practical one. This alone, I think, should be a basis for very careful consideration on the part of such makers.

In Mr. Mavor's Congress paper he pointed out that the ergs per second per cm³ of the active belt, at unit velocity in unit field was very nearly constant for most dynamos. As soon as I saw this expression it struck me that ergs per second per cm³ at unit velocity in field of unit intensity was a physical quantity of the same dimensions as current density, and Dr. Thompson elaborated this somewhat in his discussion of the Congress paper. May I refer to the matter again here?

The dimensions of erg (unit of work) are		...	$M L^2 T^{-2}$
,,	,,	Velocity	$L T^{-1}$
,,	,,	Intensity of magnetic field ...	$M^{\frac{1}{2}} L^{-\frac{1}{2}} T^{-1}$
,,	,,	Current (electro-magnetic) ...	$M^{\frac{1}{2}} L^{\frac{1}{2}} T^{-1}$

Hence ergs per sec. per cm² per unit velocity in field of unit intensity is a quantity with the dimensions—

$$(M L^2 T^{-2})\ (T^{-1})\ (L^{-3})\ (L^{-1} T)\ (M^{-\frac{1}{2}} L^{\frac{1}{2}} T) = M^{\frac{1}{2}} L^{-\frac{3}{2}} T^{-1}.$$

But current density is $(M^{\frac{1}{2}} L^{\frac{1}{2}} T^{-1})\ (L^{-2}) = M^{\frac{1}{2}} L^{-\frac{3}{2}}\ T^{-1}$.

Looking at this in another light—One conductor on the periphery of the armature moving in field of unit intensity at unit velocity has unit E.M.F. induced in it per unit length. If L be the length of the conductor in the field, m G, the total number of conductors on the armature (taking Mr. Mavor's symbols), if A be the area per wire and δ the current density, then the power manifested in the active belt will be $\delta\, m$ G A L or $\delta \times$ volume of copper in active belt.

If $\gamma = \frac{\text{vol. of copper in active belt}}{\text{vol. of active belt}}$, we may write the watts manifested in active belt as proportional to $\delta\gamma \times$ volume of active belt. Hence Mr. Mavor tells us that $\delta\gamma$ is practically a constant for all dynamos.

Let us look at equation for W on page 476. I puzzled for a considerable time before I saw the meaning of this equation, probably because I

Mr. Field.

was too lazy to read through Appendix III. In any case, this formula does not agree with that in Appendix III. This formula simply says $W = E\,C$ in a rather involved manner. $W =$ current per turn $\times$ E.M.F. per turn $\times$ number of turns, and this is independent of whether the armature is series or parallel wound. If $C =$ current per turn, $R =$ res. per turn. $C^2 R\, m\, G = A_{IIII}$, or $C = \sqrt{A_{IIII}} \,/\, \sqrt{R\, m\, G}$.

$$\sqrt{R\, m\, G} = \sqrt{\left(2\,L + \frac{D\;7{\cdot}44}{P}\right)\frac{m^2 G^2}{Q\,S_v}\,2 \times 10^{-3}}$$

and E.M.F. per turn $= 2 \times \pi\, D\, L\, B_a\, x\, n\, 10^{-8}$.

$$\therefore\; W = \frac{\sqrt{A_{IIII}}\,\sqrt{Q\,S_v} \times \pi\, D\, L\, B_a\, x\, n\, 10^{-5}}{\sqrt{2\,L + \frac{D\,7{\cdot}44}{P}}}.$$

I think the usual procedure in designing a dynamo is to fix on a current density (determined by previous experience), and by trial and error determine the number of turns per coil and wires per slot, this being to a large extent settled by the permissible reactance voltage per slot, and from that basis to arrive at the number and shape of slots. Mr. Mavor rather indicates the reverse procedure; he considers a given carcase—at each speed only a definite number of watts may be dissipated in the armature, provided the temperature rise of the same is limited. Now, determine the total iron losses at the particular speed, deduct these from the total permissible loss, and the result is the permissible copper loss. This settles then the output of the generator. I do not think that this can form a good basis of calculation, because one cannot calculate a machine from one point of view alone. The best machine from one point of view may be the worst from others; the design of such a machine is always a compromise between different conflicting requirements. We must consider at the same time heating of armature, due to itself and due to the neighbourhood of the field coils, the reactance voltage, total reaction, total copper on field magnet, mechanical considerations, etc., etc. All these considerations are inextricably entangled, as stated, one cannot design a machine from one point of view alone; it is always a case of compromise.

It seems to me that in designing a small machine the dimensions of the slot to a large extent settle themselves automatically. The turns per coil cannot be very smoothly graduated; we shall have, say, 4, 6, or 8. We prefer to choose a number which has convenient submultiples, so that the windings may be put in parallel for submultiples of the voltage. If 4 turns were unsuitable, we should take a jump straight away of 50 per cent., and go up to 6 turns, or of 100 per cent., and go to 8 turns. Which of these coils we adopt will be largely determined by the reactance voltage allowed (*i.e.*, commutation troubles). The arrangement of the wires in the slot will be largely settled by the convenience of winding the coils; the wire is round, and thus the dimensions of the slot gradually take shape. I do not say that no choice is left; it is possible to group more or less coils in one slot, and then to vary the number of turns per coil and number of slots; but there are, as a rule, not many alternatives open; we can only go in jumps, and it is usually either one thing or the other.

Mr. Field.

Mr. Mavor draws attention to the question of space factor. It is obvious that if we can get 5 per cent. more area of copper on a given armature without altering the iron dimensions, we can take 2½ per cent. more load from the machine with the same temperature rise. The space factor, or what Mr. Mavor has called Q, is a very important one. By grouping the coils together in one slot we naturally save room in insulation and increase this factor.

The old line of traction motors designed by the G. E. Co. compared with the newer types are interesting—

OLD LINE.			NEW LINE.		
G.E. 800	27 H.P.	105 slots.	G.E. 52	27 H.P.	29 slots.
G.E. 1000	35 H.P.	93 ,,	G.E. 58	37 H.P.	33 ,,
			G.E. 57	37 H.P.	33 ,,
			G.E. 51	80 H.P.	37 ,,
			G.E. 67	40 H.P.	51 ,,

I want now to say a few words *re* the curves Mr. Mavor has published. He tells us, in the first place, that the heat which can be radiated from an armature is directly proportional to $\sqrt{n}$, and in his curves he has apparently applied this empirical formula throughout the whole range of speed; in fact, down to $n = 0$. Of course, if $n = 0$, one can still absorb quite an appreciable amount of power in the armature without the temperature rising above the given limit (say, 70° Fahr. rise). I would suggest that this formula be more accurately expressed as $\alpha + \beta\sqrt{n}$, α being the permissible loss if the armature be stationary, $\beta\sqrt{n}$ the permissible excess loss due to the cooling effects of the rotation. Again, Mr. Mavor takes the hysteresis and eddy current loss in the body of the core, as $A_{,} n$, and in the teeth, as $A_{,,} n + A_{,,,} n^2$. Eddy current loss is always proportional to the square, and hysteresis to the first power of the periodicity. Now, the eddy current loss is proportional to the weight of iron and the square of the induction; hence it seems to me that the eddy loss in body of the core is equally important as that in the teeth, unless anything special occurs in the teeth. If the formulæ given by Mr. Mavor really agree with practice, it seems as if something special in the way of eddy currents must occur in the teeth, and I suggest that this may occur in their top and side surfaces. Perhaps Mr. Mavor will give us further information on this point. Does he turn the outside periphery, file the slots, and afterwards pull the plates apart, take off the burrs, and anneal the plates? Or what is the procedure?

With regard to the curves of maximum output, it is evident that if the armature be open-circuited and the speed of the generator be gradually increased, a point will be reached where the iron loss alone equals the permissible armature loss, and this will be the upper limit of speed, the output being zero. This speed is determined by the equation: $\alpha + \beta\sqrt{n} = A n + B n^2$, provided the permissible loss can be expressed by the expression on the left, and that on the right represents total iron loss.

Again, if the armature be short-circuited at a certain speed, very nearly zero, the C^2R loss will be equal to α, and this may be taken as the lower limit, the output again being zero. Between these limits the output rises to a maximum, and then decreases, as in Fig. 4. Mr. Field

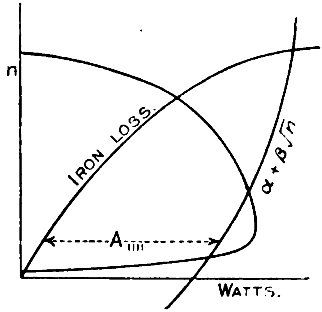


FIG. 4.

But it does not pass through zero. The iron loss and radiation curves should again be as I have shown, not as in Mr. Mavor's diagram.

Lastly, the question of enclosed motors. I am very glad this has come up. Two or three years ago some of the leading firms were standardising enclosed motors. What they did was this. They took, say, a 20 H.P. open motor, and rated it as a 15 or 10 H.P. enclosed, without any attempt to modify the design This, of course, was absurd, as the proportion of iron to copper losses could not be the best in each case.

If $V\,C$ = input of motor,
σ = fixed losses due to iron, friction, excitation, etc.,
$\tau\,C^2$ = variable losses,
η = efficiency,

$$\text{Then } \eta = \frac{V\,C - \sigma - \tau\,C^2}{V\,C} = 1 - \frac{\sigma}{V\,C} - \frac{\tau\,C}{V}$$

$$\text{and } \frac{d\,\eta}{d\,C} = \frac{\sigma}{V\,C^2} - \frac{\tau}{V}.$$

The efficiency will be a maximum when $\frac{d\,\eta}{d\,C} = 0$, or when $\sigma = \tau\,C^2$, or the fixed and variable losses are equal in amount. This, of course, is well known.

Now, if a 20 H.P. motor be designed for highest efficiency at full load, it will be manifestly very poor policy to turn it into an enclosed motor and rate it down. By re-designing it, decreasing the iron losses, and increasing the C^2R, we could get a much better efficiency as an enclosed motor. If you enclose a motor you must re-design it. In the same way, if one designs a transformer for natural cooling, then applies the air blast and rates it up, one does not get the best result: it should be re-designed. This whole problem is very interesting. If one wants to sell a machine cheap one should make the maximum efficiency at full load, because the full load loss will be smaller than if the maximum efficiency occurred at any other load, and hence for given heating full load can be rated high. It does not follow that this will be the best motor from the consumer's point of view; it may have to run light for a large portion of the time, in which case it would have been better to have a motor which had smaller fixed losses, or maximum efficiency at something less than full load. In such a case the heating effect at full load would be higher, and if the same specification were abided by

Mr. Field. it would mean a larger motor; but the consumer's current bill would be less.

Mr. Ker. Mr. W. ARTHUR KER, Assoc. M. Inst. C.E., said that Mr. Field had put forward the opinion that for a maker of an open-type motor to put covers upon it and call it an enclosed motor at a lower rating was not good practice. Mr. Field said that the designer should endeavour, for maximum efficiency of a commercial machine, to make eddy current and hysteresis losses approximately equal to the copper losses; but by enclosing an open machine, and running at a lower amperage, the copper losses were considerably reduced, while the core losses remained as before, and therefore on light loads the machine was very inefficient. The speaker stated in reference to this that it was the practice of his company and several others to enclose their ordinary open-type machine, and run it at a lower rating and at a lower speed. This was the simplest way of obtaining the result desired by Mr. Field. At the first glance one would say that by doing this one would reduce the core losses slightly on account of the lower speed; but that the reduction would not be comparable to that of the copper loss due to the lower rating. The benefit of the lower speed, however, is much more than this. The output of a machine, except in very small sizes, is usually limited by the reactance voltage. By reducing the speed from, say, 1,000 revolutions as an open motor to 900 revolutions as an enclosed motor, the periodicity is reduced sufficiently to permit (taking account of the smaller current) an addition of at least one armature turn to each commutator section, with the same reactance voltage. This means that the total length of copper on the armature is increased, while the cross section is reduced, and the copper watts become approximately equal to the core losses. This appears to be quite the simplest method of meeting the case, and from tests of a large number of machines made, both open and enclosed, using the same carcases, the efficiency of the enclosed machines is within 2 per cent. of that of the open type. This is a very small penalty to pay for the advantage of having a machine which is protected by solid iron cases from any chance of injury due to falling objects, damp, and dust. In a well-designed motor ample access is given to the commutator and brushes in order to remove the carbon and copper dust which in the course of time accumulate upon them. The speaker therefore cannot agree with the author in his condemnation of the enclosed machine. He is of opinion, however, that the enclosed ventilated motor, which has lately become fashionable, is most objectionable. If it really complies with its name and ventilates efficiently it draws all the dust and moisture-laden air in the neighbourhood over its windings and commutator, the moisture being evaporated and the dust remaining behind, the latter being practically impossible to remove without dismantling the machine.

The author states that "it is customary to treat the eddy currents in the core as being proportional to the periodicity." This is not the speaker's experience, as he can see no reason for treating the eddy current losses in the core differently from those in the teeth. Usually these losses are very small, but not always. The speaker has recently

had the design of a machine through his hands running at 3,000 revolutions per minute in which the eddy currents were considerably in excess of the hysteresis losses. The author states that "the radiation of heat from the armature is taken as proportional to the square root of the speed, and gives a diagram showing the radiation curve starting from the origin at zero speed." This does not appear to be the case. The cooling of the armature is caused by (first) radiation, (second) convection air currents, (third) air currents caused by the fanning action of the core. When the machine is standing still a certain amount of heat is dissipated by radiation and convection currents, the curve should therefore begin at a point above the origin. What appears to be really the case is, that the heat dissipated is equal to a constant multiplied by an expression which is directly proportioned to the peripheral speed. Mr. Ker.

In Appendix II. the author gives a formula for the watts radiated from the core surface, which he states is equal to the surface of the core $\times$ a constant $\times$ square root of the peripheral speed; but this does not appear to be the case. In an ordinary centrifugal fan the air discharged is directly proportional to the peripheral speed, and an armature (especially if fitted with ventilating ducts) should follow the same natural law. In that case the heat dissipated by air currents should be proportional to the air discharged—that is, proportional to the peripheral speed. The speaker believes that this is true. He has used, for a considerable time, with very accurate results a formula put forward by Mr. Kapp. It is given by Mr. Kapp in the form of temperature rise for a given surface, watts dissipated, and peripheral speed, and has been altered to give watts dissipated and English units, and is as follows:—

Watts dissipated at 70° Fahr. temperature rise $=$ ·00023 $\times$ surface of core (1970 $+$ peripheral speed in feet per minute).

It is, of course, empirical; but for small and moderate-sized machines has proved reliable; for large machines the rise in temperature is generally so small that the opportunity of verifying the formula in these cases has not been afforded. The meeting might be surprised at English units being used in dynamo calculations at the present day, but the speaker is of opinion that a judicious blending of English and c.g.s. units is of great assistance in getting out designs. He is in the habit of expressing all areas and volumes in centimetres, and all lengths in inches, the reason being that the ampere-turns per inch length in air is (very approximately) equal to twice the number of c.g.s. lines per square centimetre. By adopting this method, and having books printed giving the various formulæ required in their regular sequence, spaces being left for the insertion of figures and noting results, there is no reasonable chance of error, and a great deal of time is saved.

The author states that the tooth inductance commonly used is a maximum of 20,000 to 22,000 lines per square centimetre. That appears to be rather high, the ampere-turns required to force the flux through the teeth being excessive, and probably a density of 18,000 is more generally satisfactory. Many designers are abandoning the high densities in the teeth, as they are of opinion that a sufficiently

Mr. Ker. "stiff" field can be obtained without this. A low reactance voltage is evidently the most important requirement for sparkless commutation, and with the small polar angles which are taken by many designers at present (quite unnecessarily in the speaker's opinion) a very stiff field is not required. He had occasion the other day to make some tests on a motor which had a very "strong" armature, the cross ampere-turns under pole being equal to the ampere-turns on field required to force the flux through the air space. By means of a resistance in the shunt and by reducing the load the ampere-turns on the field were reduced to one-fifth of the normal, while the armature current was kept constant. Even under these conditions there was no sparking at the brushes, which had not been moved. The polar angle was 72 (4-pole motor), but why the machine was so insensitive the speaker could not say. The experiment, however, indicates that very heavy inductions are not necessary to ensure sparkless running if the reactance voltage is kept low (this was about 3½ volts at normal speed). The experiment was one of several on different machines, all with much the same result. In this connection he would be glad if the author would inform the meeting how he arrives at the area of the air space. Glancing through the formulæ in the appendices, the speaker cannot see that one included, though the density of the air space is used in the formula for obtaining the density in the core, and from the value of the symbol x (which is included in the same formula), the area of the air space appears to be taken as that of the poles. This cannot be the real air space area, and it would be of help if the author would give the formula he uses.

The speaker said that in the formula in Appendix III. for obtaining the length of end winding no allowance was made for different numbers of slots. As a matter of fact, the length necessary is very much affected by the number of slots and the ratio of slot width to width of tooth. In machines with two or more coils per slot (in which direction modern design for small machines, and the paper deals with small machines only, tends) the end winding can be much shorter than with machines having one coil per slot, as practically the same thickness of insulation serves for two coils in place of one, and the angle of the double helical-formed coils can be much acuter. The depth available for the outer ends of the coils also affects the length necessary, but no provision is made for this in the formula.

The author expressed the opinion that "ventilation of the cores of small machines is an expensive and, on very small machines, an impracticable expedient." This the speaker considered to be only partially correct. If the author is in the habit of milling the slots in the core, the ventilating ducts must prove a difficulty; but if the slots are notched in a stamping press the extra cost of stamping air ducts in the plates of small machines (in large machines the spider is provided with longitudinal ducts) is very slight, and, in fact, the stampers who supply the trade do not charge extra for this. The cost of distance pieces to keep the plates apart at the ducts is only a matter of a few pence per machine. The gain by having ducts is so great, increasing the cooling surface by an amount equal to the area of each side of each

duct, that the cost of the ducts is covered many times over by the extra output obtainable with the same temperature rise. The speaker uses air ducts in all armatures from 7-inch diameter upwards; under 7 inches diameter it is impossible to find space for the longitudinal ducts. He has listened with much pleasure to the paper, and the impression he has gained is that the trend of it is this, that if you have a fast running machine it is best to have a shallow slot, and keep the iron losses down; and this is possible, because a high speed requires few armature conductors, therefore less slot volume is required for copper and insulation. With a low speed a deep slot must be used, as many armature conductors and much insulation are required. Mr. Ker.

Discussion Continued, December 9, 1902.

Mr. W. B. Hird said that his name had been mentioned in connection with certain of the formulæ in the paper, more especially in connection with Mr. Field's remarks regarding them. There were two points which Mr. Field had criticised. The first was that the formula Watts radiated $= a\sqrt{\eta}$ should be $a + \beta\sqrt{\eta}$. Mr. Hird contended that both formulæ being empirical and the value of the constants having to be determined as the average of a number of experimental results, it was within ordinary limits of speed, say 1,000 to 300 revs., possible to find a value of a which in the first formula gave results quite as nearly in agreement as did any values for a and β in the second formula, whilst the simplifying of the equations was greatly in favour of the first formula. It was of course quite true that for speeds either above or below a certain limit the first formula did not represent the facts. Mr. Kerr wished to substitute "n" for the $\sqrt{n}$ in the formula $a + \beta\sqrt{n}$. In Mr. Hird's experience this would give calculated values of radiation at high speeds much in excess of the truth. The second point raised was that eddies in the core should vary as n^2, not as n: certainly eddies vary as the square of the speed, but except at very high speeds the eddies in the core are unimportant compared to hysteresis and teeth losses, and therefore the error caused by treating the core eddies as a percentage of the core hysteresis is only small. On the other hand the high complexity of the flux distribution in the core makes it very difficult to estimate the value of the coefficient if the eddies are treated, as strictly speaking they should be, as equal to $a\,W^t\,B^2\,n^2$. Mr. Field pointed out that the ergs per cubic centimetre of active belt at unit speed and with unit magnetic flux is equal to current density per square centimetre of belt area, and said that it was, therefore, not remarkable that the ergs should work out approximately equal in different designs, as this only meant that different designers worked at about the same current density. It is, however, not the current density in the copper which must be kept the same, but the current density in the copper multiplied by Q, and it is somewhat remarkable that as the value of Q is altered the current density in the copper should alter in inverse ratio so as to keep the product constant. Mr. Hird.

But his chief object, however, was to point out that the value of the paper appeared to him to be quite independent of these questions. The

Mr. Hird

curves drawn on the board and given in Fig. 2 seemed to him to be the important thing; the principle that this graphical method should be adopted for determining the best speed at which a machine should be run, or if the speed were fixed the best depth of slot to be used, is entirely independent of the particular form of formulæ used. Every designer must have some formulæ, some method of determining the iron losses and the watts radiated. If a designer preferred his own formulæ to those given in the paper, let him use them in the manner indicated, and instead of merely knowing in a vague way that if the speed gets very high the iron losses will equal the possible radiation and the permissible copper loss will become zero, and he will therefore get no output, let him plot the curves shown, using his own formulæ, and find out exactly at what speed this happens. It was, of course, perfectly true, as Mr. Field had pointed out, that this did not completely design the dynamo. It did not enable them to get a round wire into a square slot which it would not fit to any advantage, and they still had to begin by finding a suitable slot and wire to fit one another; but the curves were a valuable indication of the direction in which they should work in looking for a suitable slot.

Mr. McWhirter.

Mr. WM. MCWHIRTER said it was refreshing to see that there was still something worth discussing in the design of C.C. dynamos. Some years ago a member of this Institution had stated that a cow of average intelligence was capable of designing such a machine, as it simply consisted of two bearings, a shaft and a pulley; this notwithstanding, we had since had many excellent papers on the subject, and although we had often heard that the C.C. dynamo or, in fact, any type of commutating machine ought to be relegated to the scrap heap, still the time for this relegation instead of being within sight, appeared to be receding into the distant future, and therefore every suggestion for the improvement of C.C. machines should be heartily welcomed.

Mr. Mavor said that in his Congress paper on dynamo designing he "suggested that the essential part of the dynamo is the region occupied by the armature conductors in the magnetic field." But had not this suggestion been before the Institution for many years? Almost every paper on dynamo designing during the last twenty years had been imbued with the idea, and many formulæ had been proposed giving the output of dynamos in terms of the dimensions of this part of the machine. In this paper no mention was made of any part of the dynamo outside the armature. The paper was unique in this respect. Another striking point was that the question of commutating was hardly referred to, and we ought all to rejoice that this subject has now been found to be quite unnecessary. This was certainly the greatest improvement made in recent years in dynamo construction. The speaker once had under his care one of the largest C.C. dynamos which had then been made, the brushes for which alone had cost over 10s. per week, whereas now we had similar machines running which did not cost so many pence. Most of the so-called inventions in connection with special windings and pole-pieces on dynamos were made not only to improve the commutation, but to give a position where the brushes might be absolutely fixed and practically independent of any change in

output. These proposals had not always been successful, and the large amount of energy, time, and money spent upon the attempts in this direction had certainly not been repaid. The simple adaptation, however, of the carbon brush properly applied had brought about more improvement in this respect than all the attempts referred to, and we ought to give more credit for the great improvement due to this simple innovation. Mr. Mavor's aim seemed to be a proposal for further improvement in the dynamo, thereby increasing the efficiency by reducing the losses set forth as items 1 to 6 on page 474. Generally speaking, there was not much difficulty in arriving at the temperature of the dynamo winding at any moment, by the simple plan of noting the falling-off in the shunt current (of course maintaining a constant voltage or correcting for variation), and this would certainly give a more reliable result than the application of thermometers to the outside of windings, etc. The temperature found by the increased resistance would approximately give the mean temperature, whereas the thermometer has usually to be applied to what is in reality the coolest part of the machine. The paper was evidently an attempt to settle the question of the best dimensions for the armature slots, or to put it otherwise, "deep" *versus* "shallow" slots. There certainly must be one dimension of slot which is the best for a certain output at a given speed and a given voltage, but the best slot dimensions must vary both with the voltage and the speed, as insulation of conductor and slots bear a large proportion to the copper section, and as the voltage increased more care was necessary to maintain the insulation between the conductors themselves and between the conductors and the core. He was not clear upon the curves given by Mr. Mavor, more especially Plate 1, and as the symbols used for the various losses would require so much time to check his figures properly, he had not had any inducement to look further into the matter. He wished it were possible for writers on dynamo-designing to use a common set of symbols, a thing which would make such papers far more easily intelligible. He also thought that Mr. Mavor might have spoken of revolutions per minute instead of per second. Mr. McWhirter.

Professor MAGNUS MACLEAN said that the paper by Mr. Mavor was one of great importance, and his contentions should be subjected to all the useful criticism designers of small dynamos and motors could bring to bear on them. For his own part he only wished to draw attention to one or two points that Mr. Mavor might elucidate in his reply. In the Appendix the hysteresis loss in the teeth was taken to be proportional to $B_t^{1.6}$, whereas eddy currents in the teeth were taken to be proportional to B_t^2. Why? It was, he thought, pretty well established by experiment that the hysteresis losses reached a maximum at a flux density of about 16,000 c.g.s. lines per square centimetre, and that for higher flux densities the hysteresis loss diminished asymptotically. Still further experiments were necessary to elucidate this subject. Mr. Mavor very pertinently remarked that the "story is not yet told of all that takes place in a piece of iron under changing magnetisation." He (Dr. Maclean) had had in view for some time to rotate a disc of copper and a disc of iron in a calorimeter placed between the poles of an Professor Maclean.

Professor Maclean.

electro-magnet. If discs of different thicknesses were rotated at different constant speeds and in different constant strengths of fields, he believed very useful information could be obtained as to the hysteresis and eddy current losses that took place in the armature cores of dynamos and motors.

It was pointed out by Mr. Field that the constant, K, Mr. Mavor introduced, viz., ergs per second per unit volume at unit velocity in unit field, was equivalent to current per unit area. Mr. Field did so by substituting for each factor its dimensional expression in terms of length, mass, and time. He was a great believer in dimensional expressions, and he was of the firm opinion that electrical engineers did not devote the attention to that important subject that it deserved. But in the present case the equivalence could be arrived at quite simply.

$$K = \frac{\text{Activity}}{\text{Volume} \times \text{velocity} \times \text{flux}}$$
$$= \frac{\text{Current} \times \text{electromotive force}}{\text{Area} \times \text{length} \times \text{velocity} \times \text{flux}}$$
$$= \frac{\text{Current}}{\text{Area}}$$

Mr. Mavor.

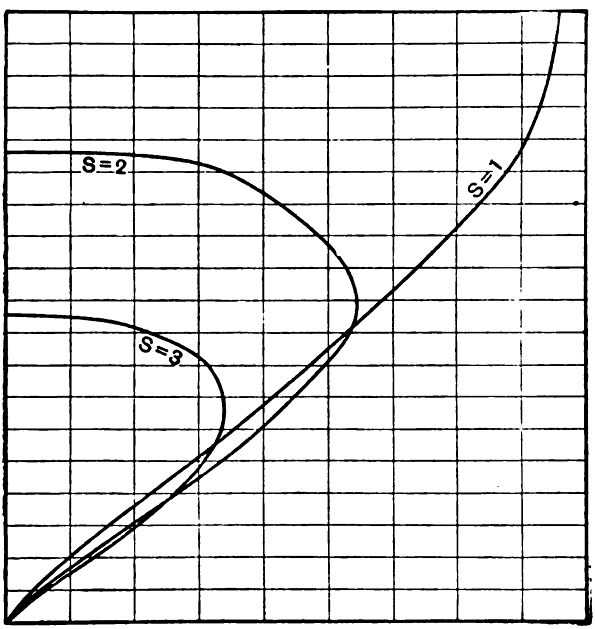
Mr. H. A. MAVOR, in reply, said that he wished to thank the members for the manner in which they had received his paper and discussed the points raised. The subject was one the interest in which was limited to a comparatively small number of the members, but it was none the less important on that account.

With regard to Mr. Field's remarks, he thanked Mr. Field for his contribution to the discussion and for the correction of certain typographical errors in the proof of the paper, and said that he had rightly understood the position adopted by the writer of the paper, viz., that it was necessary in small machines to consider the speed at which the machine had to be run with special reference to the iron losses. Mr. Field stated that the usual procedure in designing the dynamo is to fix on a current density determined by previous experience, and by trial and error determine the number of turns per coil and wires per slot, this being to a large extent settled by the permissible reactance voltage per slot, and from that basis to arrive at the number and shape of the slots. The writer of the paper agreed with Mr. Field that it is impossible to design a machine from one point of view alone, and that the design is always a compromise between different conflicting requirements. He argued, however, that if you begin by requiring an impossibility from the machine, there was not much use in going into other details. His method was to plot out the watts radiated at each speed with the iron losses, and to deduce the curves described in the paper, assuming, for preliminary purposes, unity as the value of the ratio between copper area and slot area—that is to say, assuming that the copper fills the slot.

Reference to the formulæ in Appendix III. would show that the watts output derived from this assumption must be multiplied by the square root of the actual value of this ratio to obtain the actual output of the machine. This ratio is determined by the considerations

mentioned by Mr. Field, viz., the consideration of reactance voltage and other practical requirements, but the slot width being determined by the length of the air space, and the necessity for avoiding heating of the pole-tips by eddy currents, the best slot depth is ascertained from the curves plotted as described in the paper, and it will be seen that there is not much room for choice in the other points which require to be considered, so that the actual output of the machine is fixed at a maximum which it is the aim of the designer to obtain as nearly as possible. Mr. Mavor.

Mr. Field's reading of the value of the constant used for energy generated in the active belt is quite correct, but it is not in any sense



at variance with any of the arguments of the paper. It is only another way of saying the same thing. It is necessary to point out that the assumption of value for current density is the conductor in a first approximation of the design of the machine, exactly gives away the whole case. This quantity is among the very last to be determined. The current density in the conductors is of comparatively little importance in small machines; in fact it will be seen from the efficiency formula that the efficiency of the machine may be reduced by reducing the current density in the conductors.

Mr. Field's point with regard to the watts radiated is worthy of attention, and it would probably be better to plot the curves as he suggested. On the other hand, the curve $\sqrt{n} \times$ a constant, being derived entirely from experimental results, applies only to the range of

Mr. Mavor. these records, and this is from $n = 8$ to $n = 20$, or thereby. It can be extended to wider limits if need be, but for ordinary standard machines it is not necessary to calculate the curve below $n = 8$, and properly speaking it ought not to have been drawn below this point.

The line of argument of the paper is that there are several speeds at which a machine carcase will give the same output, and that one of these speeds is the best. Approximate curves of the outputs obtainable from a 10-inch machine were shown, and are added to the Appendix of the paper. It was pointed out that in the case of the machine in question, the curves of which are plotted for an assumed unit value of Q, the space factor, the output of a machine wound with a two-centimetre slot was very different from a three-centimetre slot at the assumed speed of $n = 16$ per second, and that if any circumstance arose to increase the temperature rise, either from variation of the quality of the iron in the ore or otherwise, the use of a three-centimetre slot on this machine would be very dangerous. The use of a two-centimetre slot, on the other hand, gives an increased margin of output in the ratio of 6 to 10, as indicated by the points marked A and B respectively on the curves for the three-centimetre and the two-centimetre slots. The envelope of the curves drawn for each slot depth gives the maximum value for the output of the machine, and having determined the speed at which it is to run, the slot which gives the best output at that speed without any tendency to fall away from a straight line on the curve, for the slot chosen is the best slot to use for the machine. In the case under consideration a two-centimetre slot would be approximately the best for a speed of $n = 16$.

Replying to Mr. W. Arthur Ker's remarks, the arguments of this paper are commended to the further consideration of the members, because if they are borne out by the facts they show that each machine ought to be differently wound for each speed and output, and that a simple reduction of the speed of an open motor so as to obtain a satisfactory enclosed machine is not the right way to solve the problem. On the other hand, the line of design indicated by Mr. Ker's remarks are quite in accordance with the ordinary modern practice, but the speaker's contention was that this practice is not sound.

The author thanked Mr. Hird for his defence of the formulæ used in the Appendix, but pointed out that the correctness or otherwise of these formulæ had nothing to do with the argument of the paper, his contention being that it was necessary to examine all formulæ for determining the iron losses on the lines indicated in the paper, so as to obtain a comprehensive grasp of the conditions and avoid elaborate calculations with regard to the possible windings for a machine which left out of account altogether the principal factor of primary importance in laying out the design. The author agreed with Mr. McWhirter in the continued importance of continuous-current machinery, but pointed out that his paper had reference to small machines only.

He pointed out that the long expression referred to by Dr. Maclean

was not used for a calculation of the area of each conductor, but was a symbolic expression of the quantities on which this area depends. The formulæ given for this purpose will be found convenient in attacking dynamo design from this point of view. The author claimed for his paper that it was not a treatise on the whole subject and did not take up all the points necessary to be considered, but he wished further to commend a study of the subject on the lines indicated, having no desire to magnify the results already obtained, but ventured to think that such a study would lead to very considerable modifications along the line of improvement in the design of small machines. Mr. Mavor.

GENERAL RULES FOR WIRING FOR THE UTILISATION OF ELECTRICAL ENERGY.

1. These rules embody the requirements and precautions which the Institution has framed to secure satisfactory results with supply at a pressure not exceeding 500 volts if continuous or 250 volts if alternating. They are intended to include only such requirements and precautions as are generally necessary, but they are neither intended to take the place of a detailed specification, nor to instruct untrained persons.

2. Notice of the proposed introduction of wiring should in all cases be given to the Fire Offices insuring the risk, and to the suppliers of the electrical energy if such is to be obtained from an external source.

GENERAL ARRANGEMENT.

3. Conductors must radiate from distributing centres, and in large systems from those centres to sub-centres, so that no sub-circuit carries more than 5 amperes up to 125 volts, or more than 3 amperes from 125 to 250 volts, for incandescent lighting.

4. When protected from mechanical injury by hard metal tubes or conduits, conductors even of opposite polarity may be "bunched," and when carrying small currents from sub-centres, as in paragraph 3, they may, if without joints, be "bunched" even when the protecting tubing or casing is non-metallic. If the supply is alternating and the protection metallic, conductors must be bunched so that the sum of the currents passing is zero.

5. When one of the main conductors of a system of supply is earthed, no interruption of the current by any mechanical device is permitted in a conductor connected to the earthed main that does not also, and simultaneously, break circuit on the non-earthed conductor. Hence, to insure the current being interrupted simultaneously on both the earthed and the non-earthed wires, no switch that is not linked to another switch on

the non-earthed conductor may be inserted in any conductor connected to an earthed main.

6. No fuse may be placed in the neutral conductor of a "three-wire" system. This does not prevent the use of a disconnecting link in the neutral for testing purposes, but fuses must be placed on both conductors of two-wire circuits branching therefrom.

7. Every system must be controlled by linked main switches, which must be placed as near to the entry of supply to a building as circumstances permit, and which must be easily accessible. Subject to paragraph 6, the system must also be protected by main fuses.

8. Every sub-circuit must be protected on both poles by a fuse; and no single-pole switch may be inserted in the earthed side of a system.

9. When the wiring is such that one conductor is uninsulated at all points—such as a bare return to a concentric system—no switch or fuse may be placed in that conductor, and the said conductor must be efficiently earthed.

10. When the supply is from all three conductors of a *three-phase* system, each conductor must be protected by a fuse and the whole controlled by three linked switches.

11. When the pressure between outer conductors of a three-wire main exceeds 250 volts, the circuits connected to opposite sides of the neutral conductor must be so disposed that a person cannot simultaneously touch two points respectively in contact with the outer conductors.

12. Conductors conveying currents at pressures exceeding 250 volts must be completely enclosed in strong metallic sheathing or tubing efficiently connected to earth, and such sheathing or tubing must be electrically continuous throughout its length.

13. No switch, cut-out, connector, or other electrical appliance, may be mounted directly upon any surface of a condensing or humid nature, such as masonry, brickwork, cement, or plaster—but must, in addition to its own mount, be fixed upon a base block rendered impervious to moisture.

14. Branch fuses must be grouped together in accessible positions in sight, and should be symmetrically placed and labelled for each circuit.

15. Contact between insulated conductors and gas-pipes, or metals in contact therewith, must be prevented by non-conducting incombustible distance-pieces.

16. Gas-pipes must never be used to obtain an earth connection.

17. Switches and fuses, not in an engine-room or compartment specially arranged for the purpose, must be covered.

CONDUCTORS—CONDUCTIVITY AND SIZE.

18. The sectional area of conductors (see Table) must be greater than that determined by the heating effect of the current required for the maximum number of lamps, or other current-using apparatus, that can be used simultaneously on the circuit.

19. The size of conductors within a building will, subject to paragraph 18, be determined by the permissible drop in volts, which should not exceed 2 per cent. on lighting circuits.

20. Copper conductors should be of soft copper, and should have a conductivity not less than 100 per cent. as compared with Matthiessen's[1] standard; and where sulphur compounds are present in any part of the insulation the copper in contact with the insulation must be protected therefrom by tinning or otherwise.

21. The sectional area of a copper conductor must not be less than that of No. 18 S.W.G. wire, with the exception of the case of flexible cord conductors and wires for fittings, when the sectional area must not be less than that of a No. 20 S.W.G. wire. All insulated copper conductors having a greater area than that of a No. 14 S.W.G. wire must be stranded.

22. The table appended shows the sizes of copper conductors which will safely carry currents up to 740 amperes, and the length in yards of single conductor in circuit for each volt of fall of potential when the maximum current is in use.

CONDUCTORS—INSULATION.

23. Conductors must be specially insulated with material which does not deteriorate at the highest temperature to which it will be subjected; for instance, rubber must not be allowed to exceed 130° F., or paper—or fibre—insulation 170° F. In specially hot places the conductors should be so large that the electric heating is almost nil.

24. The insulation on any conductor other than a flexible cord must be throughout either—

(*a*) A dielectric which is impervious to moisture and only needs mechanical protection. ("Dielectric" does not include braiding or taping.) Or

(*b*) A dielectric which must be kept perfectly dry, and therefore needs to be encased in a waterproof sheath, generally of soft metal, such as lead, drawn closely over the dielectric.

[1] See Appendix, p. 513.

25. The radial thickness of vulcanised rubber must be not less than 30 mils plus one-tenth of the diameter of the conductor (see Table, column 3). The radial thickness of dielectrics of Class (*b*) must be not less than that given in the Table, column 4. The dielectric must not soften sufficiently to allow decentralisation at a lower temperature than 170° Fahr.

26. The dielectric of Class (*a*) must be thoroughly damp-proof, and that of Class (*b*) must be enclosed in a sheath of ductile material entirely impervious to moisture, which, if metallic, must be electrically continuous throughout and connected to earth.

27. The dielectric must be such that when a test-piece of the insulated conductor has been immersed in water for twenty-four hours it will, while still immersed, withstand 2,000 volts for ten minutes between the conductor and the water. Prior to immersion the test-piece must have been bent six times (three times in one direction and three times in the opposite direction) round a smooth cylindrical surface not more than twelve times the diameter of the finished cable.

28. The minimum insulation resistance should be that given in Column 12 of the Table for vulcanised rubber, and that in Column 13 for Class (*b*), the test being made at 60° F. after one minute's electrification at 500 volts, and after the test-piece has been immersed in water for twenty-four hours. This resistance must not fall more than 10 per cent. after seven days' immersion.

29. Conductors insulated as in Class (*a*) may be protected by braid or taping, prepared so as to resist moisture. Unless fixed in sight and out of reach of injury, all conductors must, further, be protected by a strong covering; and this, in damp situations, must consist of water-tight, incombustible tubes, which, if of metal, must be electrically continuous throughout and connected to earth. Means must be provided to prevent the accumulation within the tubing of water arising from condensation or other sources. Sharp bends or elbows must be avoided, corners being turned by smooth-bore round bends or suitable boxes.

30. The exposed ends of conductors, with dielectrics of Class (*b*), where they enter the terminals of switches, fuses, and other appliances, must be protected from moisture which might creep along the insulating material within the waterproof sheath.

31. Concentric conductors should in all respects conform to the requirements herein laid down for single conductors; the insulation resistance of the dielectric separating the two con-

ductors must be that given in the Table for single conductors having the same diameter as the inner conductor. The insulation resistance of the dielectric on the outer conductor where insulated, must be that given in the Table for single conductors of the same outside diameter.

32. When the mains are earthed at one point, the outer conductor of a concentric system is the conductor to be connected to the earthed main.

33. In applying the bending test to concentric conductors, the diameter of the cylinder used should be not more than twelve times the diameter of the finished cable.

34. Flexible conductors, *i.e.*, those made up of a number of wires not larger than No. 35 S.W.G., which are then insulated, may only be used for attachment to portable appliances or pendants or for sub-circuits when visible throughout their length and spaced from walls by porcelain insulators. For the wiring of fittings a strand composed of three wires of No. 25 S.W.G. may be used. The insulating material used as the dielectric must be either pure rubber or vulcanised rubber of the best quality. If pure rubber be used, it should be laid on in two layers, care being taken that these break joint. The radial thickness of the dielectric must not be less than 16 mils for pressures up to 125 volts, or 20 mils for pressures from 125 to 250 volts. The covering must be such that a test-piece not less than one yard in length cut from the conductor will withstand a pressure of 1,000 volts alternating at a frequency of from 40 to 100 periods per second applied for ten minutes between the test-piece and a similar test-piece twisted together with it, the pieces being subjected during the test to the vapour arising from a pan of boiling water placed ten minutes before the commencement of the test at a distance not exceeding three feet immediately below it.

CONDUCTORS—JOINTS.

35. Joints in conductors are prohibited except on small wires protected by fuses, viz., 5-ampere fuses on circuits up to 125 volts, and 3-ampere fuses on circuits from 125 to 250 volts. Junction-boxes must be used to connect lengths of larger conductors, and be so constructed that—

(*a*) the conductors cannot be readily short-circuited ;
(*b*) the insulation between opposite poles will not readily break or chip ;
(*c*) the connections do not heat.

If used in damp places, special precautions must be adopted to exclude moisture.

36. Joints must be mechanically and electrically perfect to prevent heat being generated. All joints must be soldered. Soldering fluids containing acid, or other corrosive substances, must not be used. The insulation of all joints in insulated conductors must be most carefully attended to.

37. In jointing conductors the braiding, tape or lead, must be carefully removed without damage to the dielectric for a sufficient length to insure a thorough union between the dielectric and the material used to insulate the joint. If the insulating material is not waterproof, it must be covered with an impervious sleeve or box, which must make a water-tight joint on each side of the junction. Care must be taken to exclude moisture during the operation.

38. Joints between flexible conductors and permanent wires under flooring or in wood-casing are prohibited.

Joints constitute a source of weakness, and they must, therefore, be accessible, and it is recommended that their positions be indicated by a conspicuous mark.

BURIED CONDUCTORS IN BUILDINGS.

39. Conductors buried in cement or plaster must be provided with protection of sufficient strength to resist a nail.

40. Conductors passing through walls or fire-resisting floors must be provided with additional protection, such as a porcelain or other incombustible tube which must be filled up with some chemically inert incombustible material, so as to prevent the spread of fire through these openings. When the end is outside the building it should be bell-mouthed and turned downwards.

CONDUCTORS—WOOD CASING FOR.

41. Wood casing must not be—

(*a*) buried in plaster or cement, nor exposed to moisture ;
(*b*) used in damp places ;
(*c*) run immediately below water pipes unless efficiently protected from drip.

CONDUCTORS—PRECAUTIONS AT POINTS OF CONNECTION.

42. Where conductors are connected to switches, fuses, junction-boxes, or other appliances, the whole of the separate wires forming the stranded or flexible conductor must make

contact with the terminal so that no loose wire or strand can project. The dielectric must not be bared back further than to allow the conductor to enter the terminals properly, and the ends of the insulation Class (*b*) should be sealed.

43. The braiding, lead, or other covering to the dielectric must be cut back from the end of the insulating material, and waterproofed. In damp places the strands of conductors, Class (*b*), should be soldered to prevent moisture creeping along the copper beneath the insulation.

44. Conductors of larger section than 7/18 must be soldered to proper lugs for connection. Where there is any possibility of strain on the lugs they must be mechanically attached in addition to the soldering.

SWITCHES.

45. Every switch, whether fixed separately or combined with lampholders or fittings, must, except as provided in paragraph 17, be encased, and comply with the following requirements:—

(*a*) Overheating must not take place at the point of contact or elsewhere, when the full current flows continuously.

(*b*) When being switched off it must not be possible to form a permanent arc. Switches should be tested at pressure and current 50 per cent. in excess of that which will be used on the circuits for which they are intended.

(*c*) It must be incapable of remaining in partial contact.

(*d*) The base must be of incombustible non-conducting and moisture-proof material.

(*e*) The cover must be of incombustible material, and must be either non-conducting, or of rigid metal, and clear of all internal mechanism.

(*f*) Where the pressure exceeds 250 volts, covers must be of metal and must be earthed.

(*g*) Handles must be insulated and so arranged that the hand cannot touch live metal.

(*h*) It must not contain a fuse.

FUSES.

46. Every fuse must be encased, except as provided in paragraph 17, and comply with the following requirements:—

(*a*) That no overheating can take place in any part when the full current flows continuously.

(*b*) That it shall effectually interrupt the current when a short-circuit occurs, and also when the current through it exceeds the working rate by 100 per cent., the current flowing under the normal pressure in both cases.

(*c*) The base of the fuse must be of incombustible, non-conducting, and moisture-proof material.

(*d*) The cover must be of incombustible material, and must either be non-conducting or of rigid metal lined with insulating incombustible material. It must be kept clear of all the internal mechanism. When the fuses are of the open type and grouped together, the case of the distribution board will be a sufficient protection provided the distance from cover to fuse exceeds two inches.

(*e*) Fuses must not be placed in wall-sockets, ceiling roses, lampholders, or switch covers.

(*f*) The fusible metal must be of such size that no conductor protected by it can possibly exceed the temperature specified in paragraph 23.

47. Separate single fuses, and not "double-pole" fuses, must be used on circuits on which the pressure exceeds 125 volts.

48. Fuses may be considered too large if they are not warm to the touch on full load, and too small if they hiss when moistened.

49. *Note:* It is recommended that hard metal be used for fuses; and that if soft wire is used, it should be soldered to hard metal contacts.

CONNECTORS: WALL- AND FLOOR-PLUGS, ETC.

50. All connectors should be capable of withstanding a test at a pressure and current 50 per cent. in excess of that for which they are intended. In damp places special water-tight connectors must be used. In cases where the fixed part of the connector is attached to a floor it must be so arranged that no dust or water can accumulate in the cavity, and that all contacts are well below the floor-level, or covered to prevent any possibility of danger from contact with carpets.

51. No connector may contain a fuse.

52. Connectors must be constructed so that they cannot be readily short-circuited. Clearances should be such that an arc cannot be started if the connector is pulled out at the time that the current is flowing. The insulation used between opposite poles should be such that it will not readily break or chip.

53. Flexible cord conductors for portable fittings must end in a connector.

54. Every portable current-consuming device must be independently controlled by a switch on the live side of the connector.

CEILING ROSES.

55. Every ceiling rose must comply with the following requirements :—

(*a*) The base must be of incombustible, non-conducting and moisture-proof material ;

(*b*) The cover must be of incombustible material, and must be either non-conducting or of rigid metal, and clear of all internal mechanism ;

(*c*) Unless it, or its base, form part of the sheathing as in paragraph 12, it must not be attached directly to a plastered surface, but must be mounted on a prepared block ;

(*d*) Its terminals must be relieved of the direct pull of the attached conductor and fitting, and be so arranged that no short circuit can take place ;

(*e*) It must not contain a fuse.

SWITCH AND DISTRIBUTION BOARDS.

56. Main and distribution switch- and fuse-boards must be made of incombustible insulating material insulated, where hygroscopic, by bushes from the supporting framework, and fixed in a dry situation, and be so placed that a fire thereon cannot spread to combustible material.

57. Live metal must be fixed at such a distance from all metal not at the same potential, or be so separated by insulating partitions, that an arc cannot be formed between the metal surfaces.

58. Connections at the back of boards must be made accessible, but, unless protected from acid fumes, must not project into battery rooms. Circuits should be labelled for identification.

59. The cases of instruments, if metallic, must be insulated from the circuits, or, if connected to one pole, they should be protected from the possibility of contact with the other.

60. Every voltmeter with its connecting wires should be protected by a fuse on each pole.

FITTINGS FOR SUPPORTING LAMPS.

61. Wherever brackets, electroliers, or standards, require to have the conductors threaded through tubes or channels

formed in the metal work, these must be of ample size and have no sharp angles or projecting edges, which would be liable to damage the insulating material.

62. Where possible, the conductors should be carried without joints through the fittings to the lamps ; but where connections at the fitting are unavoidable, special care must be taken to make the joints equal in conductivity and insulation to the rest of the work.

63. Combined gas and electric fittings must not be used.

64. When disused gas-fittings are adapted for electric light, they must be entirely disconnected from the gas-pipes.

LAMPHOLDERS.

65. Lampholders must—

(*a*) be entirely incombustible ;
(*b*) be insulated from any continuously earthed conduit or sheath not forming part of the circuit ;
(*c*) be specially designed if for currents above 1½ amperes ;
(*d*) not be hung from flexible cord conductors where exposed to the weather, but be rigidly supported.

66. Switch lampholders should be controlled in groups of ten, or fewer, by a separate fixed wall-switch.

ARC LAMPS.

67. Arc lamps must—

(*a*) be guarded by lanterns or globes, which must be arranged to intercept falling particles of carbon ;
(*b*) be insulated from their support ;
(*c*) be fixed so that their cases cannot come into contact with any metallic object ;
(*d*) have their leading-in wires protected from rain ;
(*e*) be controlled by linked switches and protected by fuses (see "General Arrangements") ;
(*f*) not be used in places where inflammable vapours or explosive mixtures of dust or gas are liable to be present.

INCANDESCENT LAMPS.

68. Incandescent lamps and their holders—

(*a*) must not be placed in close proximity to inflammable materials ; shades made of such materials

must be kept free from contact with the lamps by suitable guards; celluloid and other highly inflammable material must not be used for shades;

(*b*) if placed in positions where they are exposed to inflammable vapour or gas, should be enclosed in air-tight fittings of thick glass and have no flexible cord connections.

69. Incandescent lamps of the Nernst type must comply with the regulations of paragraphs 67 (*a*), (*b*), (*c*), (*d*), (*f*) and 68 (*a*).

DYNAMOS AND MOTORS.

70. Any dynamo or motor rated at more than one-third of a horse-power must—

(*a*) be protected from damp, dust, and mechanical injury;

(*b*) be so placed that no unprotected woodwork or combustible material is within a distance of twelve inches from it measured horizontally, or within four feet measured vertically above it, unless it is of an enclosed type;

(*c*) if supplied at 250 volts or upwards, have its frame efficiently connected to earth;

(*d*) if employed in positions exposed to highly inflammable dust or flyings, or where highly inflammable materials are manipulated or stored, be of the enclosed type, without belting or gearing penetrating the casing, with ventilating openings, if any, only in the vertical portions of their casings, protected by two thicknesses of fine-mesh wire gauze set at least a quarter of an inch apart and substantially attached to the casing;

(*e*) be controlled by linked switches and protected by fuses or circuit-breakers on both conductors;

(*f*) if a motor, have, in addition to the above, starting gear consisting of a regulating switch and series resistance, the regulating switch being fitted with a magnetic release that will automatically open the circuit should the current be interrupted.

Note.—It is recommended that all shunt circuits of motors be arranged so that the field is excited before the armature is connected, these circuits to be disconnected through a non-inductive resistance or carbon break after the armature circuit is broken.

RESISTANCES.

71. Resistances, whether used in connection with arc-lamps, dynamos, or motors, or for any other purpose, must be—

(*a*) carried on frames or supports and enclosed in cases, the frames, supports, and cases to be of incombustible material efficiently insulated from the resistances ;

(*b*) amply ventilated by means of apertures protected by fine-mesh wire gauze where there is danger of inflammable material entering them ;

(*c*) so proportioned that they cannot rise in temperature more than 240° F., nor the cases containing them more than 130° F., above the temperature of the surrounding air ;

(*d*) so fixed that no unprotected inflammable material is within six inches of the cases containing them, or within twenty-four inches measured vertically above them.

CHOKING COILS.

72. Choking coils must comply with the rules for Resistances (71, *a*, *b*, and *d*, and 76).

ACCUMULATORS AND OTHER BATTERIES.

73. The room in which accumulators or primary batteries are placed must be well ventilated.

74. Accumulators and batteries must be well insulated from earth, and protected by fuses at all points of connection between the circuit and the regulating cells, unless special precautions are taken to keep the conductors permanently apart by incombustible and non-conducting material.

TRANSFORMERS.

75. If high-pressure transformers are brought into a building they must—

(*a*) together with their switches and fuse-boxes, be contained in fire- and water-proof structures, and be accessible only to authorised persons ;

(*b*) be so protected by suitable apparatus that a leak between the primary and secondary coils shall cut the transformer out of circuit ;

(*c*) not under normal full-load exceed a temperature of 170° F.

76. Low-pressure alternating transformers or choking coils must conform with paragraphs 71 (*a*), (*b*), and (*d*), and their temperature must not exceed 170° F.

ELECTRIC COOKING APPLIANCES, RADIATORS AND HEATERS.

77. These appliances must be—

(*a*) so constructed and mounted that heat cannot be conveyed to their supports and connections, precautions being taken with regard to their surroundings as in the case of non-electrical heating appliances ;

(*b*) protected by a fuse and switch in both conductors, subject to Rule 5, connectors being so arranged that the live end of the coupling is not exposed to accidental short-circuiting or injury.

TESTING.

78. The insulation resistance to earth of the whole or any part of the wiring must, if tested previously to the erection of fittings and electroliers, be measured with a pressure not less than twice the intended working pressure, and must not be less in megohms than 30 divided by the number of "points" under test. For this purpose the "points" are to be counted as the number of pairs of terminal wires from which it is proposed to take the current, either directly, or by flexibles, to lamps or other appliances.

79. Current must not be switched on until the following test has been applied to finished work :—

The whole of the lamps having been connected to the conductors and all switches and fuses being on, a pressure equal to twice the working pressure must be applied and the insulation resistance of the whole or any part of the installation must not be less in megohms than 25 divided by the number of 30-watt lamps. When all lamps and appliances have been removed from the circuit, the insulation resistance between conductors must not be less than 25 megohms divided by the number of 30-watt lamps. For the purpose of this test, every arc light shall be considered as equivalent to 15 lamps, and every motor or heater shall be rated at one lamp per ampere, provided that no motor, heater, or other appliance may be connected to the supply of electrical energy unless the insulation of the parts carrying the

current measured, as above, is greater than 500,000 ohms from the frame or case.

80. The value of systematically inspecting and testing apparatus and circuits cannot be too strongly urged as a precaution against fire. Records should be kept of all tests, so that any gradual deterioration of the system may be detected. Cleanliness of all parts of the apparatus and fittings is essential. In testing, the negative pole should be connected with the conductor under test.

81. No repairs or alterations may be made when the pressure is "on."

EXPLANATION OF TABLE.

82. *Columns 1 and 16* give the size of the conductors in common use. Cables are shown thus :—19/16, viz., 19 wires of number 16 standard wire gauge, or 19/·082″, meaning 19 wires each of which is ·082 inch in diameter.

83. *Column 2* gives the section of the conductor in square inches.

84. *Column 3* gives the minimum thickness of dielectric as defined in paragraph 25 on vulcanised rubber cables.

85. *Column 4* gives the minimum thickness of dielectric on fibre-covered cables which require to be lead-covered, viz., cables of Class B. Special cables, such as twin or 3-core cables, are not included in this column.

86. *Column 5* gives the safe radial thickness of lead in decimals of an inch for cables of Class B. This column does not apply to vulcanised rubber cables which may be lead-covered.

87. *Column 6* gives the maximum current for wires insulated with vulcanised india-rubber laid in position within the mechanical protections allowed in the Rules, when the external temperature is higher than 100° F. The current for any conductor under these conditions may be calculated from the formula :—

$$\text{Log } C = 0{\cdot}775 \log A + 0{\cdot}301,$$
$$C = 2\,A^{0{\cdot}775}$$

(where C = current in amperes, A = area in 1,000ths of a square inch).

The maximum rise in temperature will be about 10 degrees Fahrenheit on large sizes.

88. *Column 7* gives the maximum current allowable in any situation for conductors insulated with vulcanised rubber when

laid in positions within the mechanical protections allowed in the Rules when the external temperature is normal. The maximum current for any conductor may therefore be calculated from the formula—

$$\text{Log } C = 0{\cdot}82 \log A + 0{\cdot}415,$$
$$\text{or } C = 2{\cdot}6\, A^{0{\cdot}82}$$

89. *Column 8* gives the total length in yards of lead and return of each size of conductor, causing a drop of 1 volt when transmitting the current shown in Column 6.

90. *Column 9* gives the current density in amperes per square inch corresponding to Column 8.

91. *Column 10* gives the maximum allowable current with lead-covered cables, allowing a rise of about 20° F. on large sizes.

92. *Column 11* gives the total length in yards of the conductor (lead and return) for one volt drop when the current in each conductor is that given in Column 10.

93. *Column 12* gives the minimum insulation resistance with vulcanised rubber in mile-megohms. These insulation resistances correspond approximately with those of "300 megohm grade" cables having a specific insulation of 1·4.

94. *Column 13* gives the minimum insulation resistance which is advisable in practice for fibre-covered cables lead-covered. The insulation resistance between the members of twin-conductors should be not lower than the corresponding insulation resistances in the Table.

95. *Column 14* gives the resistance in Board of Trade ohms of the conductor per 1,000 yards.

96. *Column 15* gives the weight of copper conductors of the gauge given in lbs. per 1,000 yards.

DEFINITIONS OF CERTAIN TERMS USED IN ABOVE RULES.

97. *Bunching of Conductors.*—Conductors are said to be bunched when more than one is contained within a single duct or groove.

98. *Dielectric.*—A dielectric is any material which by its nature or the method of its application to a conductor permanently offers high resistance to the passage of current and of disruptive discharge through itself.

99. *Earthed Conductor.*—A conductor is said to be earthed when it is metallically connected at one or more points to the general mass of the earth.

100. *Linked Switches.*—Linked switches are single-pole switches fixed on conductors of different polarity linked together mechanically so as to operate simultaneously.

101. *Neutral Conductor.*—The neutral conductor of a three-wire system is the conductor which is at a potential intermediate between the potentials of the outer conductors, and is common to all consuming devices.

102. *Outer Conductor.*—The outer conductors of a three-wire system are those between which there is the greatest difference of potential.

> *Note.*—This specialised use of the word "outer" must not be confused with the non-technical use of the word when applied to the conductor of a concentric main which physically surrounds the other conductor or conductors of such main.

103. *Single-pole Switches.*—Single-pole switches are switches interrupting one conductor only of a circuit.

104. *Three-wire System.*—A three-wire system is one in which three conductors are maintained at different potentials, the conductor at a potential intermediate between the highest and lowest being common to all lamps or other consuming devices supplied from the system.

105. *Uninsulated Conductor.*—A conductor is said to be uninsulated when, although not metallically connected to earth, no provision is made by the interposition of a dielectric or otherwise for its insulation from earth.

APPENDIX.

The data for the resistances and weights of copper conductors are based on Matthiessen's standard as defined by the Committee on Copper Conductors in 1899, as follows:—

> "Copper weighs 555 lbs. per cubic foot at 60° F. Its specific gravity = 8·912.
>
> "Weight per mile in lbs. = 20, 350 × area in square inches.
>
> "Weight per yard in lbs. = 11, 5625 × area in square inches.
>
> "The temperature coefficient = 0·00238 per degree Fahr., or 0·00428 per degree Cent. = 0·07664 between 32° F. and 60° F.

"A lay of twenty times the pitch diameter is adopted as a standard, and the resistance in parallel of the wires is taken as the resistance of the cable.

"The resistance of *annealed* high conductivity commercial copper at 60° F. is :—

"Resistance per cubic inch = 0·00000066788 standard ohms.

"Resistance per cubic cm. = 0·00000169639 „ „

"Resistance of 100 inches weighing 100 grains = 0·150158 „ „

"The resistance of *hard-drawn* high conductivity commercial copper is :—

"Resistance per cubic inch = 0·000000681327 standard ohms.

"Resistance per cubic cm. = 0·00000173054 „ „

"Resistance of 100 inches weighing 100 grains = 0·153181 „ „

The above formulæ give the standards, but a variation of 2 per cent. in resistance or weight may be allowed for losses in manufacture.

INDEX TO WIRING RULES.

(*Note: the References given denote the numbers of paragraphs, not of pages.*)

SHOWING MAXIMUM CURRENTS, THICKNESS O

1.	2.	3.	4.	5.
Gauge. Number of wires and gauge in S.W.G. or inches.	*Section.* Nominal size of conductors in square inches.	*Rubber.* Minimum safe thickness of vulcanised rubber.	*Fibre.* Minimum safe thickness of dielectric for Class B.	*Lead.* Minimum safe thickness of lead for Conductors (Column 4).
		Mils.	Mils.	Inch.
1/18	·001810	35	35	0·030
3/22	·001825	36	35	0·030
1/17	·002463	36	40	0·030
3/20	·003016	38	40	0·030
1/16	·003217	36	40	0·030
1/15	·004072	37	50	0·030
7/22	·004266	39	50	0·040
1/14	·005027	38	60	0·040
3/18	·005364	40	60	0·040
7/20	·007052	41	70	0·050
7/18	·01254	44	70	0·050
19/20	·01912	48	70	0·060
7/16	·02227	49	80	0·060
19/18	·03399	54	80	0·060
7/14	·03483	54	80	0·060
7/·095″	·05	59	80	0·060
19/·058″	·05	59	80	0·060
19/16	·06039	62	80	0·060
19/14	·09442	70	80	0·070
19/·082″	·1	71	90	0·070
37/16	·1176	75	90	0·070
19/·092″	·125	76	90	0·070
19/·101″	·15	81	90	0·080
37/·072″	·15	80	90	0·080
19/12	·1595	82	90	0·080
37/14	·1838	86	90	0·080
37/·082″	·2	87	90	0·080
61/15	·2455	95	100	0·090
37/·092″	·25	94	100	0·090
37/·101″	·3	101	100	0·090
61/14	·3029	102	100	0·090
37/12	·3105	103	100	0·090
37/·110″	·35	107	100	0·090
37/·118″	·4	113	100	0·100
61/·092″	·4	113	100	0·100
61/·101″	·5	121	100	0·100
61/12	·5120	124	100	0·100
61/·110″	·6	129	110	0·110
91/·092″	·6	131	110	0·110
91/·098″	·7	138	110	0·110
91/·101″	·75	141	110	0·110
91/·104″	·8	144	120	0·120
91/·110″	·9	151	120	0·120
91/11	·9504	158	120	0·120
91/·118″	1·0	160	130	0·120
127/·101″	1·0	161	130	0·120

The sizes of the conductors in col. 2 which are expressed
but are the sizes adopted by the Cable Makers' Association as the

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JOURNAL

OF THE

Institution of Electrical Engineers.

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The Three Hundred and Eighty-ninth Ordinary General Meeting of the Institution was held at the Institution of Civil Engineers, Great George Street, Westminster, on Thursday evening, February 26th, 1903—Mr. JAMES SWINBURNE, President, in the chair.

The minutes of the Ordinary General Meeting of February 12th were, by permission of the meeting, taken as read, and signed by the President.

The names of new candidates for election into the Institution were also taken as read, and it was ordered that these names should be suspended in the Library.

The following list of transfers was published as having been approved by the Council:—

From the class of Associate Members to that of Members—

Sydney Evershed.
Edgar Llewellyn Ingram.
W. F. Stuart-Menteth.
Laurence Maxwell Waterhouse.

From the class of Associates to that of Members—

Frederick William Topping.

From the class of Associates to that of Associate Members—

George Ernest Etlinger.
Archibald Ernest Grant.
Arthur Frederick Harris.
Leopold J. Harris.
Arnold Grant Livesay.
William Marsh.
Francis Samuel Miller.
Alexander Houston Weddell.

From the class of Students to that of Associates—

Samuel Blackley.
Sydney Elliott Glendenning.
Mahmoud Samy.

Messrs. W. R. T. Cottrell and W. Nairn were appointed scrutineers of the ballot for new members.

Donations were announced as having been received since the last meeting to the *Library* from the Maschinenfabrik Oerlikon, and the Relatives of the late A. T. Weightman; to the *Building Fund* from

Messrs. A. Eden, F. Heppenstall, H. W. Lee, A. P. Pyne, R. C. Quin, D. C. Wardlaw, L. Wilson; and to the *Benevolent Fund* from J. W. Fletcher, J. G. Wilson, and J. H. Woolliscroft, to whom the thanks of the meeting were duly accorded.

The PRESIDENT: Mr. W. R. Cooper, who has been the Institution's representative on the Committee of *Science Abstracts*, has been elected Secretary of the Physical Society, and therefore he can no longer represent this Institution. Mr. Kingsbury has kindly consented to take his place, but the Council particularly instructed me to mention this matter to the meeting, because we feel that the Institution is very much indebted to Mr. Cooper for the immense amount of hard work he has done as editor in past days, and the work he has most recently done as the most active member of the Committee.

At the last meeting I reminded members of the Institution that the Council would be glad to receive any suggestions of names for the candidature of the new Council. As I then explained, the Council do not bind themselves in any way to nominate people so recommended, but they will be very glad of any names suggested by members, and they will be carefully considered.

I will now ask Mr. J. Stöttner to read the paper in his name on the Nernst Lamp.

THE NERNST LAMP.

By J. STÖTTNER, Member.

Few inventions in electrical science have created greater expectations, excitement, and speculation than the Nernst Lamp, and with few have there been such immense difficulties in obtaining practical and satisfactory results.

From the time of the earliest application of the Edison glow-lamp attempts were made, first, to discover a substitute for the carbon filament; secondly, to avoid the necessity of evacuating and sealing the globe; *and thirdly*, in case of the filament giving out, to accomplish its exchange without at the same time throwing away the body of the lamp itself.

In 1877 Jablochkoff took out a patent for a lamp in which the illuminating body consisted of kaolin and similar refractory earths, which become conductors of electric current as soon as heated to a certain temperature.

Partly on account of the very low efficiency, but more particularly by reason of the necessity for very high-tension currents, this invention —in common with all other attempts—proved a failure, until Professor Walther Nernst came to the front with his lamp in the year 1898.

I have lately visited the extensive lamp works of the Allgemeine Elektricitäts-Gesellschaft, and will endeavour to make you acquainted with the development of the Nernst lamp manufactured there from its earliest stage up to its present design, for which purpose the A.E.G. has been kind enough to supply me with original samples of the lamp

in its various stages of development and design. The filaments of all these lamps are made of rare earths, principally of zirconia.

The earlier types of Nernst lamps had no automatic heating arrangement, and the filament or glower, as our cousins in America call it, had to be heated to the temperature required (on an average about 700° C.) to make it a conductor, by means of a spirit lamp or match.

The very first lamp brought out was type No. 1 (Plate I.) with a straight filament, the compensating resistance (or bolstering resistance as it is termed on the Continent) of which, consisting of a fine platinum wire, was arranged in parallel with the filament at a distance of about ¼ in.

In type No. 1A (Plate I.) the filament was bent in a similar manner to that of the first Edison bamboo carbon incandescent lamp, and was in the shape of a horseshoe. The burner of this lamp could be exchanged.

The bulb was open in order to facilitate artificial heating of the filament, as mentioned before. The bolstering resistance, to which I shall refer again later, consisted of fine platinum wire wound round two small porcelain tubes, and was exposed to the air to obtain a better cooling effect.

The filament in type No. 2 (Plate I.) was exactly the same as in No. 1A, but the bolstering resistance was wound on one small porcelain tube only, and partly covered with kaolin.

In type No. 3 (Plate I.) the resistance consisted of thin iron wire wound on a very small kaolin tube, which was sealed and enclosed in a glass tube. This tube was evacuated and afterwards filled with hydrogen gas. All these models, however, proved unsatisfactory, and platinum wire was again resorted to as a bolstering resistance, as type No. 4 (Plate I.) shows.

In this lamp the large loop is the resistance, which was prepared in almost exactly the same manner as the heater of the present day, a very fine platinum wire being wound in a spiral on a thin kaolin tube and then steeped in a solution containing kaolin. The small loop is the filament. It will be noticed that in this lamp filament and resistance are fixed for the first time on a porcelain base. This shape of resistance was in use for a considerable time and will be seen again in the later types.

The trouble of lighting the lamps by means of a spirit lamp or match, however, prevented their being brought into general use. They were exhibited for the first time in public in conjunction with some automatically-heated lamps at the Paris Exhibition of 1900, where the patentees, the Allgemeine Elektricitäts-Gesellschaft, of Berlin, had a magnificent pavilion lighted entirely by Nernst lamps. At this time the difficulties had by no means been overcome, but seemed rather only to have commenced, and it was found absolutely necessary to effect the heating of the filament automatically in order to bring the lamp into practical use.

In type No. 5 (Plate I.) the automatic heater will be observed for the first time. The filament in this type was again a straight rod, placed horizontally to the base of the lamp. The thick porcelain tube next to it contained the heating wire, and the smaller tube the bolstering resistance. Both filament and bolstering resistance in this lamp could be exchanged. The automatic cut-out was embedded in the socket. It will be observed that the magnet had great masses of iron and a

heavy armature, in consequence of which a great deal of energy was required to actuate it.

In type No. 6 (Plate I.) we see for the first time a heater in the form of a coil, in the centre of which the filament is placed. The heating coil was prepared in a similar manner to that in type No. 4, but mounted together with the filament on a somewhat larger base, and could be easily exchanged. The bolstering resistance was the same as in type No. 3 and could be exchanged, but was firmly fixed to the socket. The magnet was identical with that of type No. 5, and the glass bulb similar to that of an ordinary incandescent lamp.

Type No. 7 (Plate I.) is very similar to No. 6. This lamp was designed for 220 volts. The filament could not be arranged in a horizontal position on account of its length, and therefore both filament and heater were mounted vertically to the base.

A great improvement is shown in type No. 8 (Plate I.). Here for the first time will be observed in the bolstering resistance spirals of thin iron wire suspended free of the carrier.

Type No. 9 (Plate II.) was a departure from the usual practice, in which a loop filament was again used and a magnetic cut-out placed alongside of the bolstering resistance instead of being embedded in the socket.

Up to this time the lamps had been manufactured only in small numbers, but types Nos. 10, 11, 12 (Plate II.) and 13 (Plate III.) were now designed and for the first time produced in considerable quantities. These lamps show two distinct forms, the "A" type with large body and globe, and the "B" type with small round globe and body so arranged that it could be used in an ordinary Edison screw lamp socket.

The "B" lamps, types 10 and 11 were manufactured for an energy consumption of 40 and 80 watts and potentials of 110 and 220 volts respectively. The bolstering resistance in these types again consisted of platinum wire as in type No. 4. As on account of their small size it was impossible to combine these filaments with a modern iron resistance they were all arranged in a horizontal position. The heating spirals were mounted firmly on the porcelain baseplate, which could be easily exchanged. In these lamps the magnet of the automatic cut-out received its final shape, being marked by very small masses of iron and a very light spring, and in consequence thereof by a very small loss of energy. The "A" lamps were for higher currents up to 1 ampere, and had to be separately connected in a similar manner to that in which an arc lamp is connected.

Types 12 and 13 were designed for an energy consumption of 100 and 200 watts with a corresponding lighting capacity of 65 and 130 standard candle-power respectively. In this type the burner, as well as the bolstering resistance, could be independently exchanged. These lamps were made for 110 and 220 volts. As opposed to the "B" lamp, the filament and the heating coil were arranged in a vertical position. The design of the magnets of the automatic cut-outs was exactly the same as that in the "B" lamps. The metal cap covering the resistance was provided with ventilating slots, so that the bolstering resistance was cooled by the circulation of air.

Plate I.

(Showing Nernst Lamp, Types 1–8.)

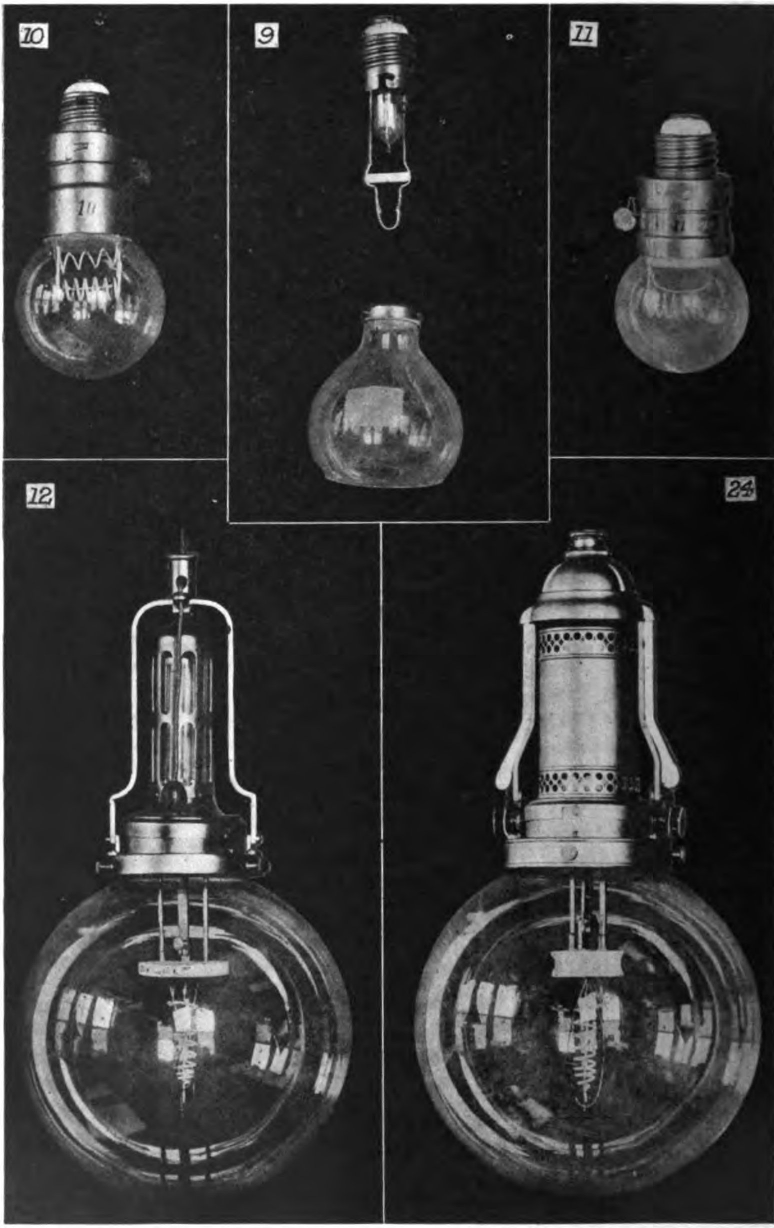


PLATE II.

(Showing Nernst Lamp, Types 9–12, and 24.)

Plate III.

(Showing Nernst Lamp, Types 13 and 25.)

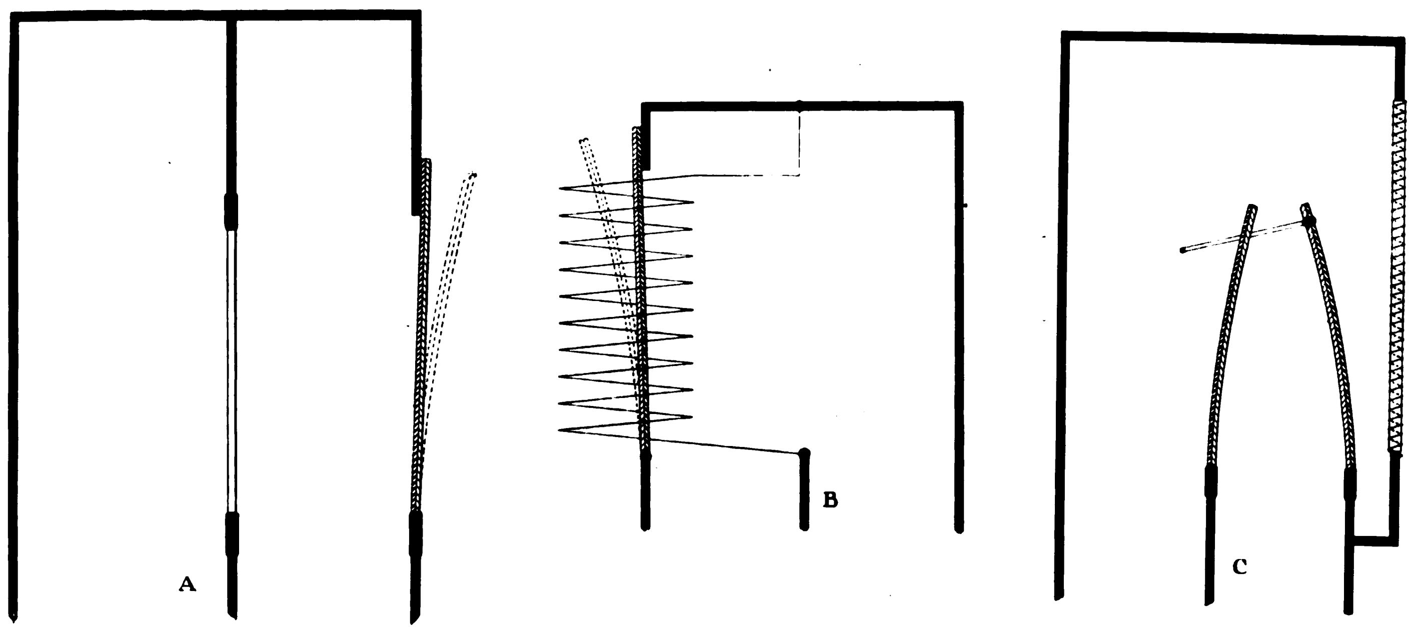


PLATE IV.

Types Nos. 14, 15, 16, 17 and 17A show the development of the Nernst lamp as a candle lamp for chandeliers, etc. These lamps do not deviate materially from those described up to now, but correspond with the ordinary lamps in each successive stage of development.

In Nos. 18, 19 and 20, the gradual reduction of the iron masses in the magnet will be noticed. The first magnet weighs about three times as much as those in use at the present day.

Nos. 21, 22 and 23 (Plate III.) show experiments in disconnecting the heater by other means than that of an electromagnetic cut-out.

Sketches A, B and C (Plate IV.) show the corresponding diagrams of current in these devices. The springs of compound metal bend to one side as soon as heated. These inventions, however, did not come into practical use and, indeed, never left the laboratory. I merely mention them to show that all kinds of researches were made with the object of improving the details of Nernst lamps.

Nos. 24 (Plate II.) and 25 (Plate III.) show the latest patterns of Nernst lamps, as now in use by the million.

No. 24 is the A type lamp. The burners are manufactured for 1 ampere up to 250 volts, and for ½ ampere, only, from 200 up to 250 volts. The metal hood is furnished with metal combs of thin sheet copper in the inner cover, for the purpose of cooling the bolstering resistance. Between this inner tube and the outer mantle are a number of tubes for ventilation purposes and to facilitate the radiation of heat.

The replacing and fixing of burners is a very simple manipulation, and can be effected by any unskilled person.

For customers who have A lamps of the old type we have designed special adapters, so that the new burners can be used on such lamps.

No. 25 (Plate III.) is the latest B type lamp, which is manufactured for ¼ and ½ ampere up to 150 volts, and for ¼ ampere up to 250 volts.

The replacement, etc., of burners is quite as simple as in the case of the A type lamp.

Nos. 26 to 36 are various bolstering resistances, all made of iron wire, sealed in glass globes which have been evacuated and afterwards filled with hydrogen. Iron wire is used on account of its high temperature correction, which makes it particularly suitable, as, for instance, should the current increase 5 per cent. the resistance of the iron wire increases about 75 per cent., thus preventing the destruction of the filament. The increase of resistance in the iron wire is nôt proportionate throughout, and it is therefore necessary that the sectional area should be chosen with a view to heating the wire to a critical temperature by the current with which the lamp is intended to burn, in order to arrive at the above-mentioned result, i.e., the balancing of current by resistance.

Nos. 37 and 38 show filaments which have burned 1,400 and 1,600 hours respectively. Unfortunately No. 37 is broken, but from No. 38 it can be easily seen that the filament has become crystallised. It is also black throughout; this discoloration starts at the negative pole and gradually extends over the whole filament. The precise cause of this crystallisation and blackening is not at present known, but we presume that it is due to electrolysis.

As to the efficiency and life of the Nernst lamp, I refer to the table of tests made at the Physikalische Technische Reichsanstalt at Charlottenburg.

A number of lamps have been under test at the Electrical Testing and Standardising Institution at Faraday House, London, since the middle of December. The results, however, are still outstanding.

A great many errors in the treatment of Nernst lamps are committed, in consequence whereof numerous complaints of short life, etc., are lodged with the suppliers; but if instructions are carefully followed a life of about 300 to 400 hours—as practical results show—may be expected. One great mistake generally made is that the current is sent through the lamps in the opposite direction to that intended, particularly in the "B" type lamp. Another mistake is to overrun the lamps, as the surplus current is then taken up by the bolstering resistance and practically the light is not in the least increased.

On the Continent the screw holder is in almost universal use, and the standard rule is to make the centre contact minus; it is therefore immaterial how frequently the lamps are taken out of their holders, as they always come back to their proper position. With bayonet lamps it is different: the poles can be easily changed by inserting the lamps the wrong way, and to prevent this the A.E.G. have designed a tool to cut out a slot, and have provided the porcelain socket of the lamp with a third pin, so that it is impossible to get the lamps into the holders the wrong way.

To determine the polarity on bayonet sockets special pole-finders are supplied, the negative pole being invariably indicated by the red appearance of the solution.

I have studied the principles and designs of the Nernst lamps manufactured in the United States, and think that we here in the Old World may pride ourselves on being at least as up-to-date as our American cousins.

Mr. Drake.

Mr. B. M. DRAKE: We are indebted to Mr. Stöttner for kindly giving us the history of the evolution of the Nernst Lamp, as worked out by the Allgemeine Elektricitäts-Gesellschaft, of Berlin, and it may be of interest to compare what has been going on in this country in connection with the same problem. As you may know, when this invention was first brought to public notice, attempts were made at a meeting at Berlin of the holders of all the patents of Nernst for the world to arrange for an interchange of experience by which the lamp might be brought to perfection in less time than would be possible if each worked on his own account. At that meeting, which Mr. Swinburne and I attended on behalf of the Nernst Electric Light Company, there were present Mr. Westinghouse, the Allgemeine Elektricitäts-Gesellschaft, and Messrs. Ganz. Two days were spent in discussing the invention, which was regarded as marking a new era. There was a serious discussion as to the result on the electrical industry when the lamp should make its appearance. One influential member said there was no doubt that if these lamps were put upon the market indiscriminately the supply companies' business throughout the world

Mr. Drake.

would be affected to a serious extent: the companies would suddenly find that their output was halved, with the result that it would be impossible for them to pay dividends for the year. It was further stated that it would be impossible for the wiring contractors, however numerous they might be, to wire the additional houses which would at once rush for the electric light, owing to the fact that the cost of lighting would be halved. All sorts of methods were suggested as to how the lamp should be put upon the market gradually, so as not to upset the electrical industry. These hours of discussion, however, were somewhat wasted, for providence looked after the electrical industry. As soon as we had finished our discussion, we all went home and discovered that none of us could make the lamp at all. Unfortunately, owing to international jealousy, we were unable to come to any arrangement by which we could arrange an interchange of improvements, and the result was that each tried to work out the lamp for himself. There are on the table specimens showing the progress of the Nernst lamp as we designed it in England. Unfortunately we had not the unbounded resources of the Allgemeine Elektricitäts-Gesellschaft, and we were blessed with a boisterous set of shareholders, who would not leave us alone, besides which we had to manufacture out of England. Had it not been for these drawbacks I think we should have put our lamp on the market as soon as, if not sooner than, the Allgemeine Elektricitäts-Gesellschaft. Some of the results which we were able to produce are shown in the curves exhibited. These are the mean results of a number of tests which were made; and you will see from the Curve Fig. A that we were able to produce lamps which

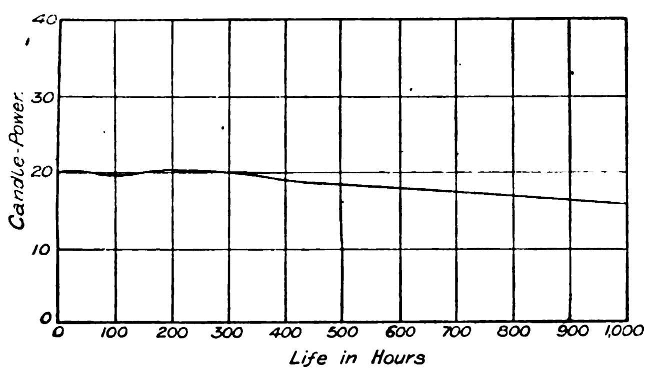


FIG. A.

started at 20 candle-power, and after 800 hours had only dropped to 16·5. The tests were very carefully taken, and will compare favourably with the results obtained by any carbon lamp which has ever been made: the average watts being 2·7 per candle throughout the whole period. The next diagram (Fig. B) shows the drop in candle-power of large lamps of 200 volts, starting at 130 candle-power and ending at about 80, with a mean efficiency of 2·3 watts in 700 hours,

Mr. Drake.

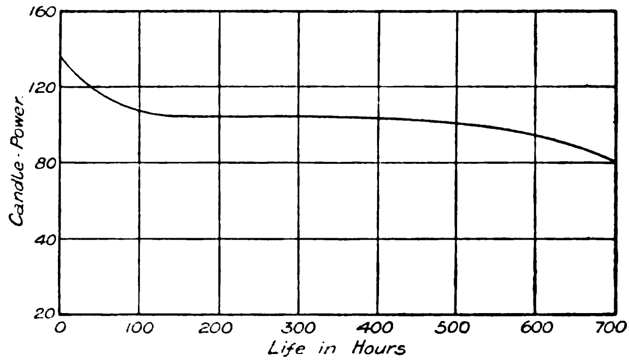


FIG. B.

the Curve Fig. C shows the rapid way in which the volts absorbed by the resistance increase with the smallest increase of current. The result is that when these series resistances are used with Nernst lamps you get a more regular candle-power with variations of voltage than with the carbon lamp. The Curve Fig. D shows the percentage variation of candle-power of the carbon lamp and the Nernst lamp, with different voltages. It will be seen from this that in the Nernst lamp the candle-power does not increase to anything like the same extent as in the carbon lamp. The carbon lamp, with a rise from 100 to 115 volts, has increased in candle-power in a ratio of 100 to 230, whereas the Nernst lamp under the same increase of pressure has only increased to 130. The iron resistance may be looked upon as one of the turning points in the Nernst lamp, and it will be used to advantage in series with the ordinary carbon lamp on traction circuits where the voltage is not very regular. In Mr. Stöttner's paper there are one or two points, probably slips, to which perhaps he will not mind my referring. Near the top of page 521 he talks of the resistance being arranged in parallel with the filament; I think he means in series.

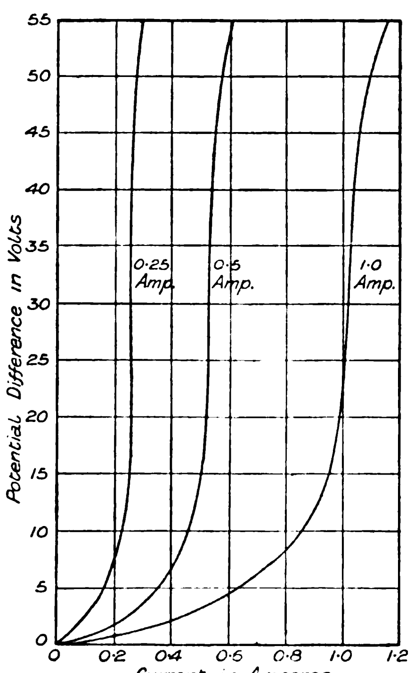


FIG. C.

Mr. Stöttner.

Mr. STÖTTNER: As a matter of fact the resistance and filament are arranged in parallel, but electrically, of course, they are connected in series.

Mr. Drake.

Mr. DRAKE: The next point is with regard to the claim of the Allgemeine Elektricitäts-Gesellschaft to be the first to show an automatic lamp. Mr. Swinburne will bear me out that the lamp originally shown at the Society of Arts, which is on the table, is automatic, the heating hood being lifted by a powerful magnet away from the glower. Also automatic lamps made by Ganz were shown in 1899, at the Royal Society. The Ganz lamps are also on the table for the inspection of members who would like to see them. The lamps which are alight now are some of the products of the Nernst Company. I would ask Mr. Stöttner to look at one of them with duplex glowers, because the Allgemeine Elektricitäts-Gesellschaft might do well to adopt it. We have not seen any of their make arranged in this way, and for street lighting they are very suitable because a single glower hardly gives enough light for street purposes, whereas the two just suffice. The Westinghouse Company have not up to the present produced a continuous-current lamp, Mr. Westinghouse having concentrated his attention on the alternating lamps, and, curiously enough, we found the alternating a much more difficult problem than the continuous. The Westinghouse lamps, which are also on the table, consist of a large number of small glowers; I presume he found difficulty in baking the large glowers, which is a difficult problem, and required a considerable time to solve. Mr. Westinghouse fuses the conductors into the ends of his glowers in a way which is different from that adopted by others, which is apparently better for alternating glowers. Messrs. Ganz started very energetically on the Nernst lamp, and the specimens shown on the table are very creditable examples, considering the time at which they were made. But as soon as they found the enormous outlay which would be necessary in order to bring the Nernst lamp into a practical state, they apparently got frightened and

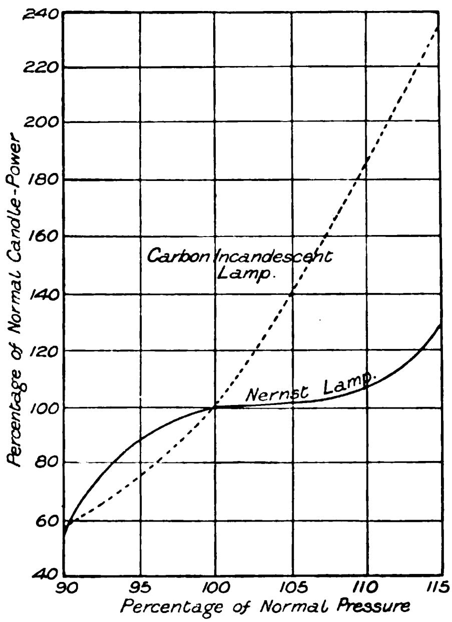


FIG. D.

Mr. Drake. left it alone altogether. We, for commercial and company reasons, have made arrangements with the Allgemeine to manufacture for our districts, and therefore the Allgemeine must be given the full credit for being the first in the world to put the Nernst electric lamp on the market in a condition in which it will meet commercial requirements.

Mr. Hammond. Mr. R. HAMMOND: I was hoping that the general body of the members would take the opportunity presented to them of having these leading experts on the Nernst lamp in the same room with them, to do a little heckling. And I am surprised at the backwardness of those who, I am sure, have so many questions to ask. Possibly, however, they will come on a little later in the evening. With regard to my attitude towards the lamp—and I think possibly it is the attitude of most of us—I feel that the ideas which were prevalent originally that the introduction of a lamp of very much higher efficiency would greatly damage our industry, are absolutely chimerical. The more cheaply we can utilise the energy which we produce, the more cheaply we can give light, and the more important will our industry grow. I had the pleasure of visiting the Buffalo Exhibition, and I was very much struck with the splendid exhibit of George Westinghouse; I spent more time in that portion of the exhibition than in any other portion, and I came back to England feeling that there was no reason why we should not start in this country street-lighting by means of Nernst lamps. Now, I am much interested, as I am sure you all must be, to hear from Mr. Stöttner that the whole question of the efficiency and life of the lamp has been settled by the tests made at the Physikalische Technische Reichsanstalt of Charlottenburg. You tell that to a town councillor, and unless he can get his friends to vote him a sufficient sum to go and visit these works himself, he wants the efficiency demonstrated on the spot. I therefore undertook for my friends and paymasters at Hackney to carry out a mile of street lighting on the Nernst system; and I was anxious to do so, not that I disregarded the wonderful results that were achieved by the Physikalische Technische Reichsanstalt of Charlottenburg, but because I felt that if the Nernst lamp was going to supersede the old-fashioned lighting which prevails in the streets of the United Kingdom, it would do so after practical results in the streets, rather than in the laboratory of the Physikalische Technische Reichsanstalt, that very excellent institution at Charlottenburg. Now, we have got a mile of street lighted, and in due course I was called upon, in conjunction with the resident electrical engineer, Mr. L. L. Robinson, to give a report as to the extension of the lighting to the whole of the 125 miles of streets in Hackney. Well, of course, as a consulting engineer always anxious to extend the scope of one's work, I was naturally tempted to say, Go in and light the whole mileage. But with due regard to a character which it is so difficult in these days to keep, I felt that it would be well that I should lay before the councillors of Hackney some actual results. And I, knowing their attitude, did not drown them with those achieved by the Physikalische Technische Reichsanstalt of Charlottenburg. I had to tell them how much per annum each lamp was likely to cost them on the basis of the life—or want of life, because you cannot tell the length of life until it

Mr. Hammond.

is dead—of those that had already been put up. You see, gentlemen, how far removed from science one sometimes has to be. And finally I laid before them this report. It is not all Physikalische Technische Reichsanstalt; there are one or two other things in it, and I shall have very much pleasure in presenting it to the Institution, which will be even a greater pleasure than reading it all through to you to-night. So that if it be deemed worthy, or if any portion of it be deemed worthy by the Editing Committee to constitute a sort of supplement to the scientific contribution that has been so ably made to-night, it is at the disposal of that Committee. But what I found was this:—First, that of these lamps, which were placed roughly about 42, 43, 45 yards apart, 40 lamps going to the mile, the first one finished his life in 130 hours. The cause of this failure was failure of flex connected to the glower. Now I am sure you will all agree with me that having a gentleman before us who is so well acquainted with the reason of flexes failing, he will be able to give us some idea of how we shall be able to arrange that in future the flexes connected with the glower do not fail. I may say that by the commercial arrangement which has been referred to by Mr. Drake, all the lamps were obtained from the Electrical Company, and it is therefore for Mr. Stöttner to tell us why in No. 1 lamp, which we thought was going to last so efficiently for 800 hours, the flex failed in 130 hours. We had, of course, to fix another lamp in its place, and the second lamp, up to the time of the making of these tests, lasted 930 hours, and he is going on lasting. With regard to the No. 2 lamp in the street, it was going merrily on after 542 hours. No. 3 lamp had to have a good deal of attention paid to it. We had men carefully patrolling this mile the whole time, so as to be able to get accurate results. The first lamp fixed on No. 3 post disappeared in 34 hours because there was a fracture of the glower at bottom contact; and that is the constant fault we have discovered, at all events at Hackney. This report, I may say, is dated February 2nd of this year. The second lamp fixed on No. 3 post gave a life of 96 hours, and in that, again, there was fracture of glower at bottom contact. The third lamp put in there lasted 453 hours, and died from failure of heating-coil due to faulty action of auto-cutout. We put in a fourth, and that disappeared in 150 hours; he went back to the old complaint, and, like his grandfather and his greatgrandfather before him, he died from fracture of glower at bottom contact. And the fifth lamp took up the running, and at the time of the test was 241 hours old. I am not going to weary you by reading the history of the whole of them, but the awkward thing is this, that the lives vary considerably. It reminds you of a chapter in Genesis, because some of them lived to such an advanced age; they vary from 1,070 hours and still young, to 15 hours and dead and gone. And the 15-hour one died from failure of the heating coil. We put another one in his place, who only attained a life of 30 hours, and he died from failure of the heating-coil. Well now, these figures, which I think you may take as absolutely reliable, can be summarised as follows. The total number of burners tested to full life was 67. The total burner hours, including only such burners as failed, was 20,499; the average life of the burners, that is to say the

Mr. Hammond.

dead ones (as we cannot get their average lives till they die), was 305 hours. Taking that as the basis of the life, I was compelled to get these results out in advising as to whether I could conscientiously recommend the Vestry to permit me to light the whole 125 miles of streets by this means. We found that these lamps gave their 80 candle-power pretty consistently with the half an ampere on a 240-volt circuit. I will take the working cost of 3,940 hours per annum, debiting the current at 1¾d.—as a matter of fact it was 1·7d.—debiting them with renewals on the basis of the life shown by these experiments, 11·5 burners and one resistance and one globe, sundry stores and labour. We thus get a certain net cost of working. The lamps then have to be debited with the interest on the repayment of capital on the basis of a ten years' loan at 3½ per cent. plus 8½ per cent., equals 12 per cent., a total sum of £5 17s. 9d. per annum. Well now, in this country the town councillors [of course not the electrical engineers (nothing in the way of electricity is too dear to them), who may consider that £5 17s. 9d. would be a very proper expenditure per lamp for the sake of having the Nernst lamp] think that that figure does not compare favourably with the price which would hold at all events if the lamps lasted as long as they do at Charlottenburg. I think we may ask Mr. Stöttner to help us in his reply to explain the causes of these failures, because, speaking for myself as representing Hackney, I should be only too delighted if these failures did not occur, and if the whole of those 125 miles of streets were lighted with that lamp. And I think that what applies to Hackney applies also through the country. We cannot do with a lamp that has not a uniform life. In the early days of the incandescent lamp, as we recollect, and our President will remember one or two episodes with regard to it, the difficulty was not that of making the lamp—our President made them in large quantities—but the difficulty was that of getting them uniform. If you attempt to put in lamps for street lighting some of which last 15 hours, and some of which last 1,000 hours, it puzzles even a consulting engineer, electrical as he may be, or otherwise, to determine the proper number of renewals which he has to provide for; because you cannot have street lighting with certain lamps out and certain lamps in. The disinclination to push the Nernst lamp throughout the country is, I think, largely due to its not being a truth-teller; he does not always do what his brother did yesterday. If we can get all the members of the family to live the same life, even if it is not 800 hours, but 790, or 665, we shall have attained very much nearer to its adoption than we have got to-day.

Professor Ayrton.

Professor W. E. AYRTON, F.R.S.: I will only say one word, as it is getting very late. I want to ask one question. Mr. Hammond has dealt in a very facetious way with the attempt to light a street in Hackney with the Nernst lamp; but the point I wish to deal with is the one which Mr. Hammond has passed over so easily. He has only dealt with failure arising from mechanical causes. No doubt those are very serious for any practical system of lighting, but with improved manufacture those failures can be overcome. But what I want to deal with is the point which he passed over, namely, that these lamps do

give the 80-candle-power light during the whole of their life. Now, my experience has been the opposite. It is a small experience, I grant as far as lamps that I have used myself is concerned, but it is not a small one if one looks at the Nernst lamps in shops and various other places. And I would like to ask one of the numerous experts whom we have the pleasure of seeing here to-night on the subject of this Nernst lamp, why the practical Nernst lamp does not follow any such curve as shown in those diagrams. If the English Company were able some time ago, as I understood Mr. Drake to say, to make Nernst lamps which in 800 hours only fell from 19 candles to 16·5, why is it that such lamps are not made and sold at the present day? One other question is, what is the cause of the falling off of the light of a Nernst lamp? I should like to know that very much. One knows that in the case of the ordinary glow lamp it is due to a change in the surface of the carbon filaments, by which it becomes a worse radiator of light, and sends off the energy at a lower temperature. Does anything like that occur to some extent on the Nernst filament? Does its surface change so that as it ages, say after 100 or 200 hours, it gives off energy at a lower temperature? Or what is it that happens? Is it a change in its nature which causes what must be the common experience of many present, namely, the light to fail and not to remain, as I wish it did, following the curve such as Mr. Drake has indicated? Professor Ayrton.

Mr. M. SOLOMON: I should like to add a few remarks to what has already been said on the Nernst lamp, especially with reference to Professor Ayrton's comments on the candle-power curves shown by Mr. Drake. Of course one does not always get such good results as these, especially so good as those in the curve in Fig. A, which represents the mean result of tests on three lamps. That curve does drop a certain amount, and the curve in Fig. B drops rather more, but perhaps the average curve obtained with the commercial lamp of to-day drops more than either. Still I would point out one fact with reference to judging the performance of the lamps by those which one sees burning in shops, namely that in the first part of the curve there is a very marked drop in candle-power from about 130 to 110. My experience is that there is always a drop corresponding to that, though not perhaps always so great, and sometimes a little greater. The result is that after the first 50 hours the light from a Nernst lamp seems to change a good deal in colour on account of this first drop. The light is a very white one at first and remains white during the whole life, but one notices a considerable difference in shade if two lamps, one new and one 50 hours old, are observed side by side. But after that drop the candle-power remains fairly steady, as shown by the curve, which is quite a typical one. When the curve drops off sharply towards the end it is a sign that the lamp is about to fail. Mr. Solomon.

It is interesting to note in connection with the curves in Figs. C and D showing the behaviour of the iron resistance and the increase of candle-power with increase of voltage, that one may actually lose in efficiency by over-running a Nernst lamp. The reason is obvious when you think of it, for if the lamp is over-run by 15 per cent. the candle-power is only increased very slightly, but the volts taken by the

Mr. Solomon.

resistance are increased by a very great amount. The result is that the percentage of the total volts, and therefore the percentage of the total watts, absorbed by the resistance is very much greater, and the actual over-all efficiency of the lamp I have found usually falls when the potential difference at the terminals is increased. This is clearly shown by the curves in Fig. E, which are for a half-ampere 200-volt Nernst lamp. It will be noticed that the total watts per candle increase slightly when the supply pressure is raised above the normal. Therefore it is of course not only inadvisable but useless to try to get more out of a Nernst lamp by over-running it. The curves for the iron resistance have already been referred to by Mr. Drake, and also by Mr. Swinburne in his presidential address; they are very remarkable curves, and the Nernst lamp, by leading to the invention of this iron resistance, has given us what is in some ways a new piece of electrical apparatus, which may be of great use in other classes of work. One

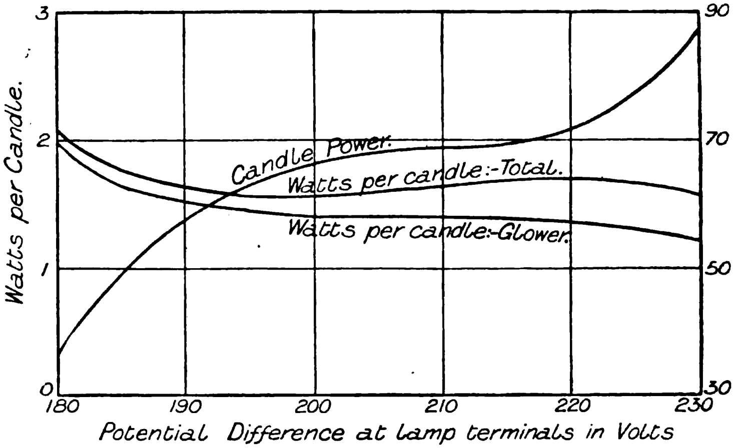


FIG. E.

can, for example, use these resistances in series with an arc, and one can get certain results by so doing which it is very difficult to obtain in other ways. If a resistance of this sort is used it is possible to run an arc with a very low current more steadily, and on a circuit of lower voltage than is possible with an ordinary resistance. I have tried this experiment, and succeeded to a certain extent, though there are certain difficulties in the way. The explanation is clear if one considers the curves for the arc which were first published by M. Blondel, and which Mrs. Ayrton has made familiar to us all. The resistances can also be used with ordinary glow lamps, and it might be a great advantage to use them with the standard incandescent lamp described by Professor Fleming. It would do away with the objection which must militate against the use of a carbon lamp as a standard, namely, that the candle-power is so sensitive to the voltage; by using a resistance of this sort one gets a curve similar to that for the Nernst lamp in Fig. D, and one

can get much better working results for practical purposes in this way and can dispense with the trouble of having to use a potentiometer. Mr. Solomon.

I should like to refer to one other matter. Mr. Drake called your attention to the two-glower lamp which is shown on the table: there is also exhibited another two-glower lamp in which the glowers are arranged in series, so that it runs direct on a 400- or 500-volt circuit. This lamp has been run and tested, and it worked extremely satisfactorily on a 500-volt circuit.

Professor AYRTON: Will Mr. Solomon add, to the interesting information he has given, one fact? The lower curve is of such enormous importance that I wish to ask this question. It is a curve showing that under some conditions the Nernst lamps are as good as far as their life is concerned, as a very good ordinary carbon glow lamp, but giving a higher efficiency. I want to ask, did you require much more heating to make that particular Nernst filament glow? Did you expend much more power in your heating coil than you do with an ordinary commercial lamp so as to start the glowing of the filaments which were used in those six lamps? Professor Ayrton.

Mr. SOLOMON: In answer to Professor Ayrton, I may say that those lamps were perfectly ordinary Nernst lamps, and had exactly the same heating coil as the commercial lamps which the Nernst Electric Light, Ltd., were then making. This coil took practically the same current as the modern commercial lamp made by the A.E.G. Mr. Solomon.

Mr. E. B. VIGNOLES: I want to ask one question with regard to a point which has not yet been touched upon this evening. It has regard to the liability to damage due to variations in the voltage on the lamp terminals. With the instructions which the Allgemeine Elektricitäts-Gesellschaft send out with their lamps is a statement to the effect that the voltage on the lamps must be kept steady. My experience of these lamps is limited, but I have found that with the ordinary, more or less unsteady, voltage which is provided in my factory for the purposes of lighting the lamps gave out in a very short time. Will Mr. Stöttner tell us to what extent the voltage may be allowed to vary with impunity, and whether the rapidity of variation in the voltage has any effect on the lamps or their resistances? For instance, if I put the lamp on to a dynamo driven by a gas engine which is varying frequently to the extent of, say, 5 per cent. of its voltage, is the lamp likely to give out quickly? It would appear from the breakdowns to which I call attention that the fine iron wire is run at such a temperature that quite moderate variations of voltage are sufficient to destroy it: and this defect seems serious, in view of the fact that on any supply a temporary rise of voltage is liable to occur. Mr. Vignoles.

Mr. A. A. C. SWINTON: Another point with regard to which I think it would be desirable to have further information is, the comparative results that can be obtained with these lamps with continuous currents, and with alternating currents. Personally, I have had a satisfactory experience of their working with continuous currents in my office. But in other places where I have had them tried and the current is alternating, with a frequency of 80, the results have not been good at all. Now, what I am anxious to know is this: Is this difference in Mr. Swinton.

Mr. Swinton.

result due to something inherent in the alternating current, or is it due to what I think may possibly have been the fact, that with the alternating current the voltage was not quite as steady? I have my office in Victoria Street, and I am supplied by the Westminster Company, whose voltage is exceedingly steady, but I rather fancy that there is something in alternating current which does not agree with these lamps. That is only surmise on my part, however. With regard to the falling off of the candle-power, the scientific aspect of the question has been mentioned by Professor Ayrton. Now the filaments of these lamps are made of materials the same as, or analogous to, those used for incandescent gas mantles; and it is well known to everybody who uses incandescent gas mantles that these mantles fall off very much in candle-power in course of time. I think the reason they fall off is also known. I believe I am right in saying that the Welsbach mixture of which these mantles are composed is about 99 per cent. of oxide of thorium and 1 per cent. of oxide of cerium, and it makes an enormous difference what the exact proportion of cerium is; 1 per cent. makes all the difference in the world. I understand that the cerium is more volatile than the thorium, and that consequently after a time the cerium has a tendency to disappear. In fact, I believe that the ordinary practice of the manufacturers of incandescent gas mantles is to put in too much cerium to begin with, so that really you get the best effect at about the middle of the life of the mantle. At first sight one might think that a similar effect may be the reason for the falling off in the candle-powder of these Nernst lamps, but I wish to put forward a reason which I think makes that exceedingly doubtful. About two or three years ago I made some experiments, which were communicated to the Royal Society, upon the luminosity of incandescent mantles; the mantles were not exactly like those made for ordinary use, but were made very thick, though manufactured in the same way. I heated them to bright incandescence by bombarding them with cathode rays in a vacuum tube; and I found that whereas in a Bunsen gas burner a mantle of pure oxide of thorium gives only something like one-eleventh of the light that is got with a mantle made of the Welsbach mixture, pure oxide of thorium when bombarded with cathode rays gave practically the same amount of light as the Welsbach mixture. There was a slight difference, but the difference was estimated at not more than 5 per cent. We had a patchwork mantle made, half of one and half of the other, and when we bombarded it equally all over we could barely see that one half was brighter than the other. That goes against the theory of evaporation and consequent alteration in the mixture being the cause of the falling off in the light when the heating is effected by anything else than a gas flame, and I am inclined to suggest that it is probably a change in resistance more than anything else that causes the light to diminish; that the electrical efficiency remains more or less the same, but that the current goes down, and with it the light.

I think this is a most interesting subject, and I have a great belief in the future of these lamps provided that, as I have no doubt is the case, the defects mentioned by Mr. Hammond can be got over by improved manufacture. Further, I think that this question of improved

lamps is one of the most important subjects which can be discussed by this Institution. Mr. Swinton.

Sir HENRY MANCE: With reference to the inquiry as to the amount of current taken to warm up the heater, I may say I have tested these lamps for some thousands of hours at my private residence, and have found that the heating current was rather more than that which the lamp took after the heater was cut out of circuit. With regard to suitability for alternating currents, my house is connected to the mains of the Brompton and Kensington Company, which supplies alternating current at 100 volts, the pressure being extremely regular. I daresay I have tried at least 20 or 30 of these lamps; I have found their life varied from 150 up to 800 hours. One of the causes of failure, as already stated by Mr. Hammond, was that the lead up to the glower failed just at the point of contact; and I made the suggestion that the contact should be arranged in the form of a ring, so that if the lower portion of the ring gave way there would be still remaining the upper portion of it, and the life of the lamp would be thereby prolonged. I noted the current which all these lamps took very carefully, and I think the statements which have been made by the inventor and those interested in the exploitation of the Nernst lamp have been fully borne out. As chairman of a company which supplies electric current, you might perhaps think I am afraid of the effect that the lamp might have on our revenue. But I myself welcome anything which will cheapen and popularise the use of the electric light. There is no doubt that the lamp takes one half the current of the present lamps, but I think that long before the conservative British public have taken to the use of the Nernst lamp they will have been educated up to requiring twice the amount of light. Sir Henry Mance.

There is one rather important point which perhaps the author might assure us about, and that is, how the lamp stands transport? I made some experiments myself with the replacement pieces in the earlier days, when the lamp was nothing like so perfect as it is now. The results of these experiments were not altogether satisfactory. This is a most important point, as the lamps have to be despatched to the furthest corners of the world.

Mr. DRAKE: I would like to answer Professor Ayrton's question. The bottom curve was taken with lamps which started with about 2 watts per candle, instead of 1·7. Everybody tried to make the Nernst lamp do more than it could do; and we made experiments to see if it would not be better in the end if we started at 2 watts, rather than 1·7 which gave such a rapid drop in candle-power. We certainly got a better result than is obtained from the lamps which are now being put on the market. Mr. Drake.

The PRESIDENT: We have had this evening a very interesting discussion. We have had Mr. Stöttner, who represents the German manufacturers of this new industry; and then we have had Mr. Drake, who not only represents the English Company, but is really more than an ordinary Director, for he has done an immense amount of the actual detail work himself with the Nernst Company. And we have had Mr. Solomon, who, with Mr. Sheppard, has also done a great deal of The President.

The President.

original work. I wish we could have had something from Mr. Sheppard too. We have not heard anything from the Ganz people on the subject, and we have not a representative here from the Westinghouse Company to tell us what is going on abroad. Before calling on Mr. Stöttner, I would like to say, partly in reply to Professor Ayrton, that the manufacture of these filaments is exceedingly difficult, not only as a matter of ordinary manufacture, but as a matter of very intricate chemistry. One reason why the English Company, though they did not make many filaments and lamps, got, in some cases, particularly good results, was the enormous care they took over the chemical preparation. Any one who is familiar with the chemistry of the rare earths knows it is exceedingly difficult to purify many of them. Some of them can only be purified by continual re-crystallising. And in any case the purification of zirconia, which is one of the chief components, is very difficult. As to the other part of the filament, it is really a group of earths. You can buy "yttria" from a manufacturing chemist, but you can never guarantee that any two bottles contain the same substance. They are mixtures of the same group of oxides, and it is very difficult to know exactly what you are getting. First, there is the mechanical question, and then there is the chemical question. It is apparently, exceedingly important to get the material out of which the filament is made, in a given physical condition, especially to get it sufficiently fine. A slight difference in this way made a great difference in the life and the change of resistance of the filaments.

As to why a lamp should go down in life when, apparently, it is controlled by a resistance which will practically keep the watts in it constant, or nearly constant, that raises a very interesting question. I do not want to contradict Mr. Campbell Swinton, but I think the argument used by him ought to have the negative sign put before it, because the conditions in the case of incandescent gas are exactly the opposite of what they are here. In the case of the incandescent gas lamp, if you increase the emissivity of the mantle you lower its temperature and eventually its candle-power. But the mantle gets more energy and gives more out, because it gains more from the gas, and the whole question is different. What I think probably happens in the case of the Nernst lamp is, that when the glower lamp gets a little old the platinum from the contacts gets into the body and you notice a slight graying of the filament, and this means an increased emissivity and light-radiating power at a given temperature. And if you keep the watts constants it radiates energy at a lower temperature and probably gives less light. Mr. Swinton's experiments in bombarding thoria are not in the least conclusive, either as regards the Nernst lamp or with respect to incandescent lamps for gas. When you are bombarding you cannot tell whether the surfaces are at the same temperature, though they may look so. If you take the trouble you can find on purifying zirconia that eventually you can get a material which you can make into mantles for gas lamps to give almost no light, but they will give plenty as Nernst lamps, and they will give plenty of light when they are bombarded. But that is a different thing, because when you are bombarding you have not necessarily got them at the same temperature.

Earl RUSSELL (*communicated*): Not being able to get into the room to take part in the discussion, I am compelled to send some observations in writing. The Nernst lamp is a very fascinating invention, and the account by Mr. Stöttner is very interesting, as I do not doubt the exhibits were if I had only been able to see them. The lamp is economical, and the light given by it is of a very pleasing quality. But I am afraid a great deal has yet to be done in making the burner run for a sufficient time. I have two Pattern A 1902 Nernst lamps, and my experience with them has been unfortunate. The lamps are 105-volt, and they are run from accumulators only in which the usual pressure is 101 to 102 and never exceeds 104, so that they are not over-run. Nevertheless, I find that instead of a life of, say, 300 hours, as stated in the catalogue, the average life has been something like 20 hours. The longest that any burner has run is about 3 months during the lighter part of the year, representing perhaps 180 hours. On the other hand I have had two burners going the next day after being put in: two which refused to light at all, and three or four which had gone in periods varying fron 9 hours to 40 hours. It is only fair to say that so far the Electrical Company have been most generous in replacing these early failures without charge, but of course one cannot say how long that will go on. They practically always break at the same place, that is the spiral part near the bottom. Another objection to their commercial use at present is the limited range of candle-power, *e.g.*, you cannot get more than a 60-candle lamp on a 100-volt circuit. Although the replacement is easy, still it involves time and annoyance (particularly if it has to be done in the dark) and the fetching of a pair of steps, besides the cost of 2s. 6d. a burner. Until, therefore, a longer average life can be given to the burners, I fear the lamp can hardly be regarded as a success for use in private houses. Earl Russell.

Mr. A. WILSON (*communicated*): I am disappointed to find in the paper no statement as to the average life of the burners and resistances of the Nernst lamps as at present placed on the market, and should be glad if the author would give some information on that point. The Company who have introduced these lamps have stated in one of their pamphlets that the life of the burner averages 400 hours, but experience with a considerable number of lamps leads me to believe that 200 hours is a long life, and even that can only be attained by running the lamps considerably below the total volts for which the combined burner and resistance are marked. For example, in a factory in which over 100 lamps are used, with 220-volt burners and 20-volt resistances and with *never more* than about 240 volts at the lamp terminals, the engineer in charge stated that the average life of the lamps was about 40 hours. By using a 255-volt combination, *i.e.*, 235-volt burner and 20-volt resistance, and consequently under-running the lamp by 15 volts, the life has been raised to about 200 hours, or about half of what it is supposed to be, with, of course, a corresponding reduction in the efficiency of the lamp. Mr. Wilson.

The lamps undoubtedly give good light and are of high efficiency, but the unreliability of the burners and the amount of attention required in making replacements seems more than to balance any

Mr. Wilson. economy which they are supposed to effect. I am quite unable to reconcile the statements which have been published as to the life of the lamps with my own experiences and those of many others under ordinary working conditions, and take this opportunity of asking for a statement on the matter from one who is apparently intimately associated with the manufacture of the lamp.

Mr. Stöttner. Mr. J. STÖTTNER, in reply, said: With regard to the remark made by Mr. Drake about two filaments in one lamp, the construction is shown in Fig. F.

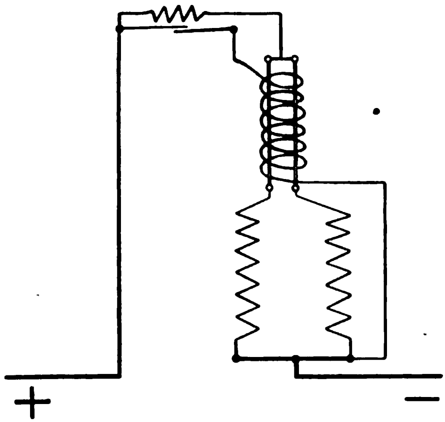


FIG. F.

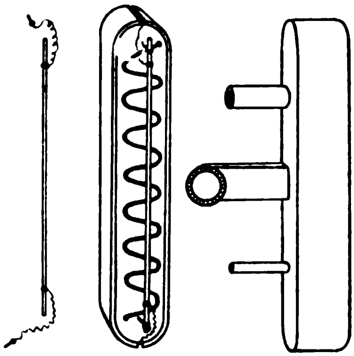
We put two filaments, which are connected in parallel, inside the heater, the current passing through one automatic cut-out to the other pole. One or other of the two filaments will be heated first—it is immaterial which—and as soon as one is incandescent the heat radiating from it will start the other filament and make it also a conductor, so that there are two filaments and one conductor. Another advantage of this arrangement is that if one filament breaks, or for some reason goes off, the other is always intact and will act as if nothing had happened.

The burners with horizontal filaments are a further novelty, they are shown in Figs. G, H, K, and L.

The filament is in front of the heater, so that all the light radiates directly downwards; they can be arranged in any number. In these lighting bodies the filaments can be taken out and easily exchanged, the complete burners being fixed in the body of the lamp as in the present design. The filaments are exceedingly simple and provided with flexible conductors, which carry a small plug on each end for connecting up. One hundred filaments can be got into a match-box.

Mr. Hammond, I am very glad to say, got about the same results as the Physikalische Technische Reichsanstalt, which worked out the average life of a lamp at about 450 hours, while Mr. Hammond got 305 hours. Had he had such clever experts to handle the lamps at

Hackney as they have at the Physikalische Technische Reichsanstalt, the results would doubtless have been still better. The reason why the flexible at Hackney and many other places has failed is a very simple one. Mr. Stöttner.



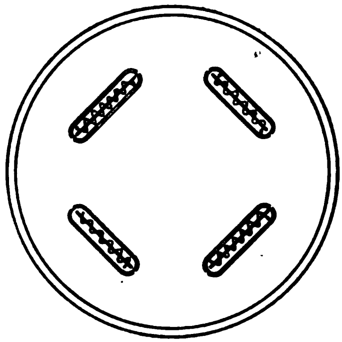


FIG. G. FIG. H. FIG. K.

The heater-coil, Fig. M, expands somewhat as soon as it is up to temperature, and if the flexible wire *a*, which conducts the current to the filament, is bent and touches the heater, it either burns through at *b*, should there be a bright spot in the heater spiral, or it burns the heater wire through, as the resistance from *b* to *c* is very small. There would,

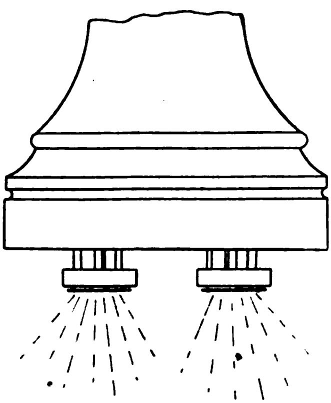


FIG. L.

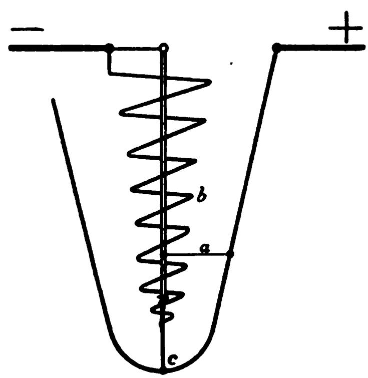


FIG. M.

however, be no difficulty in taking such a slight precaution as to examine the filament after insertion. If the lamp does not light up, the automatic cut-out does not act properly. The filaments and heaters must be examined before they are put in, and if the heater does not cease glowing as soon as the filament is incandescent, the contact-spring of the automatic cut-out sticks and the inside of the lamp must be examined.

Mr. Stöttner.

As mentioned by Mr. Swinburne in reply to Professor Ayrton, the efficiency-curve of the lamps which Mr. Drake showed is very high. We have not found such very high efficiency in ours. The light certainly does go down after a lamp has been in use for a considerable time, and the filament takes longer to heat up than it does when it is new. The efficiency drops considerably because of the blackening of the heater-coil and further on account of the crystallisation in the filament, as is shown by a filament on the table before me, which has burned 1,600 hours. As to the variation of voltage, 5 per cent. does not make any material difference to the life of a lamp, but it is preferable for it to go down than up. There was one station mentioned, however, where the variation is a good deal higher than 5 per cent. There may be a 20 per cent. variation. If the voltage rises too high, the result is that the bolstering resistance burns through. It acts as a kind of safety-fuse to the lamp if everything else is properly arranged.

As touching the question whether alternating- or direct-current lamps are the better ;—*theoretically*, alternating-current lamps should be better but *practically* we find that direct-current lamps give greater satisfaction. Whether this is because at the works the demand for alternating-current in proportion to that for direct-current lamps is about 1 : 500, and less experience has been gained, or whether there is some other ground for this, I cannot say. The breaking of filament is generally due to mechanical causes. Either they get knocked about, or they break through vibration or through some other part of the lamp not acting, as already mentioned. The electrolytic effect on the filament will in every case be exactly the same. There is no reason why one filament should burn out more quickly through electrolysis than another.

One speaker mentioned the packing and transport, which is a very serious question, under which we have to suffer greatly. As a test of average breakage we took two packages and tumbled them down four flights of stairs. On examination we found in one case two burners broken out of 200 and in the other case five broken out of 400, which I do not think is a very great percentage. With the new packing it will be less still. The old packing was much less suitable for rough handling in transit. I once caught one of our boys tossing three of the old-style round boxes with burners like a juggler, which at once explained to me why some of the filaments break; and other people may have similarly playful boys in their employ.

The President.

The PRESIDENT: I will now ask the meeting to pass a very cordial vote of thanks to Mr. Stöttner; and I have his authority to mention that he hopes to present to the Institution museum, samples showing the early history of this lamp.

The vote was carried by acclamation.

The PRESIDENT announced that the scrutineers reported the following candidates to have been duly elected, viz. :—

Member.

Wilson Hartnell.

Associate Members.

Frank Bradford.
Ashton Bremner.
Henry Coulson-Crawford.
James Cuninghame.
Albert William Davies.
Raymond G. Mercer.
Andrew Home Morton.
Frank J. Robins.

Associates.

Augustus George Ashton.
Malcom Rayner McClure.

Students.

Arthur McL. Atkinson.
Herbert Frederick H. Blease.
John Henry Clarke.
Ernest Francis Cutforth.
James Floyer Dale.
Walter Hugh St. A. Davies.
Oswald J. Davis.
Harold W. Fulcher.
Henry J. Golding.
George Goodwin.
Ernest James Harper.
Laurence E. C. Harrison.
Herbert H. Harter.
David Cecil Henderson.
Frederick Richard Hobley.
A. T. S. Hore.
James G. Horgan.
E. Laubach.
Horace Hamilton Leage.
William E Cato Liebert.
Wyndham d'Arcy Madden.
Arthur Cecil Morrison.
Ernest William Moss.
Llewellyn Digby Odlum.
Hugh Prideaux.
Hubert G. Ross.
Henry Eustace Sayer.
Herbert John Scale.
John Franklin Shipley.
Chas. Francis Simpson.
Benjamin Spalding Smith.
Joseph James K. Sparrow.
Wm. T. Tallent-Bateman.
David Alan Trickett.
Eric Charles B. Walton.
Eric Gordon Waters.
Thomas Douglas W. Weston.
Arthur Penry Williams.
George Stewart Wilson.

NEWCASTLE LOCAL SECTION.

INAUGURAL ADDRESS OF THE CHAIRMAN.

By Mr. J. H. HOLMES, Member.

(*ABSTRACT.*)

(*Address delivered November* 17, 1902.)

In addressing you at this, the third inaugural meeting of the Newcastle Local Section of the Institution of Electrical Engineers, I wish, in the first place, to thank you for the honour you have conferred upon me by electing me to the position of your Chairman for the ensuing session.

I have no doubt that with your cordial support and assistance I shall find the duties appertaining to the office as agreeable as they are honourable, and that our united efforts will enable us to uphold the status of the Institution and make the session a success. In the remarks which I have the privilege of addressing to you by way of opening our proceedings, I propose to glance at the influence exercised by the great activity and rapid development of electrical engineering upon other branches of the engineering profession.

We all have the honour of belonging to the noble profession of the engineer to which modern civilisation owes so much. For, whether it is within the sphere of the domestic circle or without, in the strenuous life that daily confronts us, there is scarcely a comfort or a convenience that exists to the realisation of which the engineer has not largely contributed. Engineering has been defined as the art of directing the great sources of power in nature to the use and convenience of man, and therefore the engineer is interested in every investigation and discovery in the whole realm of science—his occupation is the most catholic of all. No sooner does an abstract theory become a demonstration than the engineer seizes it and applies it to man's uses.

Some discoveries burst upon us with a blaze of light attracting universal attention, and inventions follow with lightning speed, whilst others develop so slowly as almost to pass unnoticed.

The branch of engineering with which we are so intimately concerned, whilst most far-reaching in its consequences, is, when measured by the mere lapse of time, but of recent growth, yet, measured by its phenomenal progress, is quite ancient, and already embraces so many distinct branches that it has become practically impossible for one man to keep pace with the developments almost daily occurring in its many sub-sections.

Young, however, as the profession of electrical engineering is, I think we may justly claim for it, that it has exerted a greater

influence upon engineering as a whole than any other individual branch, and we may profitably spend our time by glancing at a few instances of the kind.

A dynamo, as we all know, is the agent by which mechanical power is converted into electrical energy. The prime mover is usually a steam engine which has a reciprocating motion, which, by the aid of a crank, is converted into a turning movement. By the very nature of things an unequal torque is the consequence, leading to a pulsatory motion of the dynamo. There is no more exacting duty for a steam engine than that of driving a dynamo for any purpose, but particularly for lighting, where a pulsation or rising and falling in the intensity is most distressing. Hence in the early days to drive a dynamo by means of the existing engines was like driving a square peg into a round hole, and the steam engineers were immediately confronted with the problem of how to get a uniform angular velocity which was extraordinarily important in running alternators in parallel. It is interesting to recall the various methods employed to meet the case. How eagerly the problem was struggled with more or less satisfactorily in many different ways.

The early dynamos were run at high speeds obtained by belt-driving through gearings or countershafts, which was soon recognised as wasteful of power, and the difficulty was met by increasing the engine speeds, which drove out the large long-stroke slow-moving heavy engines in favour of small short-stroke quick-moving light engines driving by belting direct from the flywheel. But this was not enough, because dynamos had a variable load, hence the makers of small engines were compelled to introduce improved governors and heavy flywheels. These took the form of high-speed throttle governors spring-controlled, only to be superseded by automatic expansion governors, which, in their turn, were replaced by shaft governors revolved at engine speed.

Heavy flywheels on engines used specially for driving dynamos for traction purposes, where the alterations in load are both frequent and rapid, did very good service, securing a relatively constant angular velocity for that class of work.

To sum up, the dynamo with its high speeds forced on the balancing and governing of steam engines to a point that was never dreamed of as necessary before.

Another problem was that of lubrication. Continuity of run over long periods called attention to the need for unfailing lubrication, the oil cup of old being superseded by centrifugal oilers, and a few hours' run being lengthened out into fifteen or more, and finally to continuous running, as in the marine engine. This led to the employment of pipes and wipers fed from oil-cups, and later from a central oil-box with sight feeds. Then to independent oil-pipes to each bearing surface, conveying oil at a pressure of 20 lbs. to the square inch, maintained by a force pump. And perhaps in the most advanced way in enclosed engines such as the Willans or Chandler, where the moving parts practically splashed about in a bath of oil and water, effectively lubricating all the bearing surfaces. However, all experience having

shown that the balancing of parts, the perfection of lubrication continuity of run, small occupation of valuable space, and absence of great watchfulness as essentials in electrical machinery in up-to-date power-houses, it is brought forcibly home to every one that in Parsons' turbo-generator, which has been gradually developing of recent years, these qualities are embodied, combined with a reasonable steam consumption, to so great a degree as to bring the Hon. C. A. Parsons' invention into the foremost rank of all prime movers, and I am sure I voice the feeling of all in being proud to note that our esteemed member has been awarded the Rumford Medal by the Royal Society in recognition of his important work. Useful as this steam turbine is in electrical work, its application to marine propulsion bids fair to rank as a still greater achievement.

Measurement of Power.—The simplicity and exactitude of electrical measurements has exerted a very great influence upon questions relating to the efficiency of steam engines, both as regards steam consumption and the internal losses in the engine itself.

Water Cooling.—How to cool water for condensing purposes, that great aid to the economical application of steam power, is one of the electrical engineer's difficulties in cities where cooling ponds and running streams are absent. This has been met by the introduction of cooling towers, economical at their load, and certainly a fairly successful mode of meeting what is a difficulty in most cases.

Gas Engines.—Strange as it may seem, it is nevertheless true that it was many years before the electrical engineers could convince the gas-engine makers that the pulsation in lighting from gas-driven dynamos was not inherent to the dynamos.

In the Otto cycle method of working, where the compression of the mixed gases before ignition is a great improvement, in the single-cylinder engine, as only every fourth stroke is effective (the other three absorbing energy stored in the flywheel), a variable angular velocity results. This is met by high speeds and very heavy flywheels placed on the engine, which is the right place, and not on the dynamo spindle, which is the wrong place.

As the heating of gas-engine cylinders is proportional to the work done, over-heating had to be met by water jacketing, involving increased tank capacity and more room for the extra cylinders, a condition unknown in intermittent work for which the gas engine was in the main designed in the first instance.

Quite recently, large power producer-gas engines, such as the "Diesel," consuming crude petroleum finely sprayed into the combustion chamber, have been introduced highly suitable for driving dynamos with economy.

Transmission of Power.—In the transmission of mechanical power I claim that the electrical engineer has exercised extraordinary influence.

Belting.—The increase of transmitted power through using higher speeds in running shafting and belting was but dimly recognised until forcibly brought under notice by dynamo working.

Inequalities in laced belting joints caused jerks in running over

dynamo pulleys, and led to endless sewn joints for smoothness in running and dynamo slide rails for taking up the slack caused by stretching.

Then to obtain greater equality and avoid slip the leather link belt was devised, each link becoming a joint. The extra weight of this form of belt was of advantage when used with the top side slack, as it should be, as its sag embracing a larger arc of contact on the pullies reduced slip, even when the shafts were comparatively close together. But a laminated belting composed of long strips of leather placed on edge side by side until the required width is obtained, then closely sewn through, best fulfils the requirements for the transmission of power.

Small Steam Pipes.—The great economy in the electric transmission of power by means of wire conductors has opened the eyes of the owners of works to their losses in that most wasteful method of power transmission by distributing steam from a central point by means of steam pipes, either underground or overhead, to small engines at a distance. Enterprising men, especially shipbuilders, have realised large economies, first by diminishing labour by concentrating their generating plant in one shop, and, secondly, by replacing their notoriously inefficient scattered small steam engines by electric motors deriving their energy from compound or triple condensing engines. The electric motor only draws energy as the work needs it, the waste in distribution by electric conductors is trifling, the daily upkeep is small, and the arrangements are simple in control. These advantages presage the early supersessions of steam-power distribution, and also of hydraulic-power distribution. Lifts or elevators are now mostly electrically worked, and cranes and capstans for docks and warehouses are rapidly following suit.

In overhead travelling cranes the usefulness of three motors *versus* one motor is moving in favour of three motors, because of the peculiar feature of electric driving previously mentioned—the absence of loss of energy excepting during actual running of the motor which exactly fits intermittent work.

The slow speed of the chain drum has called for improvements in gearing, leading to the use of raw-hide gearing, double or triple thread-worm gearing running in an oil bath, of friction gear, and in some cases the epicycle train.

The propulsion of vehicles is of immense importance, and the electric influence is daily more marked. Indeed, it is evident that we are on the threshold of huge developments in this direction.

Even the large railway companies have been stirred, and it looks as if Newcastle, the birthplace of the locomotive, will also be the pioneer in the use of electric haulage. If not, it is safe to predict that the electric tramways service, which is now developing so marvellously, will still further diminish their receipts.

Electric tramways must work a complete revolution in social life, inasmuch as their cheap rapid and pleasant transit brings town and country into closer touch, spreading the population over a wider area, discrediting jerry-built flats in favour of garden cottages.

For all automobile work electricity is by far the cleanest and most agreeable agent, and much development may be looked for in this direction.

Socially, the influence of the electric light has been most marked; it has lent brilliancy to internal lighting by the use of the arc, and for decorative purposes the glow-lamp is supreme, whether it be for advertisement or for social gatherings. It has stimulated the use of light; that which used to be considered sufficient is now considered inadequate, what would formerly poison the atmosphere and dirty all decoration now simply makes home cheerful, and vitiation of the air is overcome whether in the theatre or the home.

The reaction upon the gas industry has been immense; the gas man's monopoly has gone, and with it his lethargy, leading to the regenerative gas-burners of Siemens and Wenham, and the Welsbach light; and, latterly, the Kitson modification of the Welsbach, with its low cost and rivalry of the electric light? Similarly in fittings, the artistic designs in graceful lines to please architects have stimulated similar improvements in gas-fittings. And as to ocean steamers, what would they be without the electric light? and shortly what will they be without electric winches, windlasses, fans, which are fast superseding small engines and leaky steam-pipes?

Then, again, what an influence electric search and other lights have had on the mercantile marine, doubling the capacity of the Suez Canal without cost, where 90 per cent. of the vessels that pass through save fourteen hours per trip by its agency.

The coal miner now signals, blasts, and lights electrically; also pumps, hauls, drills and cuts his coal electrically.

The gold miner converts water power into electric power, and by its agency crushes ores and uses it for all mechanical purposes.

Edison separates iron ores formerly useless for the smelter, and electricity plays a prominent part in reducing and refining, whilst the electric furnace also produces aluminium, sodium, carborundum, and calcium carbide now, and will, probably, other substances shortly.

Of course of the oldest of the electrical industries, telegraphy, and its development telephony, much can be said; what was a luxury is now a necessity almost as much as the sun itself, for by its commercial agency the business of equalising the products of the world for feeding its inhabitants is consummated.

As for wireless telegraphy, with which Marconi's name is linked for ever, it should be as useful to fleets at sea as the ordinary telegraph is to railways on land, and what more may be in store only time will reveal.

Again in the case of the body, for nervous troubles, for baths, for cauterising, for ameliorating skin diseases and looking into our interiors with Röntgen rays, how can we do without it?

I trust this rapid glance at some of the instances of the influence of electrical on other branches of engineering has served to remind us that we belong to a profession which, though young, has played an important part in the march of progress recently, and promises a more rapid advance than ever now. Electricity now permeates every

branch of business; it is no longer an abstruse science, and every one who takes an intelligent interest in what goes on around him must acquire some knowledge of its behaviour and uses.

By creating new needs electricity has stimulated the other branches of the profession in a very marked manner, quite beyond the stimulus of competition in their own lines.

It would be too big a subject to enter upon the question as to how far our present standard of civilisation would be possible if electricity were absent from our calculations, and I must leave this for each of us to think out for himself.

If I have succeeded in impressing upon any one of my hearers a higher opinion of the usefulness and importance of the work upon which he is engaged, and of the nobility of his profession, I shall be amply repaid for what, after all, are, I fear, but feeble efforts to do justice to a theme which is worthy of a much abler pen than mine.

BIRMINGHAM LOCAL SECTION.

INAUGURAL ADDRESS OF THE CHAIRMAN,

By Mr. Henry Lea, Member.

(*ABSTRACT.*)

(*Address delivered December 10th, 1902.*)

From time to time, particularly since the advent of electricity as a producer of light and a distributor of motive power, we English engineers have been charged with being laggards. I am not one of those who believe that we are in a bad case, and I propose to try this evening to ascertain whether the state of one industry at all events, namely the electrical industry, is calculated to afford encouragement to ourselves and the country generally, or whether the gloomy views so often expressed are in any sense justified. My aim this evening will be to obtain a general idea whether the Electrical Industry is growing, or standing still, or going backwards. The period selected for scrutiny comprises the years 1898—1901, four years being quite enough, in my judgment, to show which way the stream is flowing.

The first point that I shall bring before you relates to the growth of the manufacture of steam engines for driving dynamos. Nineteen large firms were good enough to respond freely to my inquiries. The results which I shall place before you are the collective totals of the returns of all the firms who have been good enough to give them in each case, and whilst they must not be taken as being in any sense the totals of this country's production, they may, I think, be fairly regarded as representative of the industry generally.

Steam Engines.

Confining myself then at present to steam engines made by nineteen firms only, I find the following results :—

1. *Numbers of Steam Engines turned out for the sole purpose of driving Dynamos :—*

1898.—967.
1899.—1,649, an increase of 71 per cent. over 1898.
1900.—1,655, an increase of, say, ½ per cent. over 1899.
1901.—1,836, an increase of 11 per cent. over 1900.
1901 shows an increase of 90 per cent. over 1898.

2. *B.H.P. of the same Engines in nearest round numbers :—*

1898.—86,000.
1899.—168,000, an increase of 96 per cent. over 1898.
1900.—210,000, an increase of 25 per cent. over 1899.
1901.—295,000, an increase of 41 per cent. over 1900.
1901 shows an increase of 243 per cent. over 1898.

The extremely rapid growth in horse-power as compared with the much slower growth in numbers of engines indicates that the sizes of the engines are increasing. Thus,

3. *Average Horse-Power per Engine* :—

1898.—89 H.P. each.
1899.—102 „ „ an increase of 15 per cent. over 1898.
1900.—127 „ „ an increase of 26 per cent. over 1899.
1901.—161 „ „ an increase of 24 per cent. over 1900.
1901 shows an increase of 81 per cent. over 1898.

I think you will agree that, at all events as regards steam engines for producing electricity, there has been nothing during the last four years to dishearten the people of this country

CONTINUOUS-CURRENT MACHINERY.

Now let us turn to the output of dynamos and motors, taking first continuous-current machines. In this connection the number of firms furnishing returns is 17 only.

1. *Numbers of Continuous-current Machines, including both Dynamos and Motors* :—

1898.—2,540.
1899.—4,736, an increase of 86 per cent. over 1898.
1900.—5,095, an increase of 7 per cent. over 1899.
1901.—6,799, an increase of 33 per cent. over 1900.
1901 shows an increase of 168 per cent. over 1898.

2. *Power of Continuous-current Dynamos and Motors in Kilowatts* (nearest round numbers) :—

1898.— 39,300 K.W.
1899.— 65,200 K.W., an increase of 63 per cent. over 1898.
1900.— 83,600 K.W., an increase of 28 per cent. over 1899.
1901.—107,400 K.W., an increase of 40 per cent. over 1900.
1901 shows an increase of 174 per cent. over 1898.

A fact that has become evident during the last four years has been the growth in the use of multipolar machines for continuous currents. The matter is not very well understood, and manufacturers have been largely in the hands of consulting engineers. A multipolar machine can be constructed at low cost to give very high efficiency as regards C^2R losses, but it is a much more difficult matter to get over iron losses. The last four years have seen a great increase of knowledge on this subject. The correct construction and subdivision of the magnet cores, the correct proportioning and the number and size of slots in the slotted armature cores, have during the past four years received increasing attention, so that if we now compare the most economical multipolar machine with the most economical bipolar smoothed core armature of ten years ago, we find the former has at length equalled the

economical efficiency of the latter; whereas for a long time following the first introduction of multipolar machines, although they were always a better mechanical job they were, on account of their heavier iron losses, behind the older machines in efficiency. Consumers as a rule did not appear to understand this, and demanded the same high efficiency from the modern multipolar that they were in the habit of obtaining from the old smooth-cored bipolar, but, for the foregoing reasons, manufacturers failed for a long time to turn out multipole dynamos or motors within the specified limits of efficiency.

Ten years ago the iron and core losses of the bipolar machines made by several leading firms were under 1 per cent., but the C^2R losses were only kept down to 3 per cent. by the profuse and costly use of copper in the armatures and fields. In these days the same total efficiency is obtained, but the distribution of losses is reversed; the C^2R losses can be kept down to 1 per cent., while the core losses are with difficulty reduced to 3 per cent.

Alternating-current Machinery.

The makers of this class of machinery are comparatively few in number, and as regards three-phase work have not long been engaged in the production of such machines. The most that the returns show is that this branch of British industry is receiving some attention, though real activity of growth has yet to come. Grouping together single-phase, two-phase, and three-phase machines, the following are the results of the returns (from five firms) of generators and motors combined :—

1898.—35	machines,	output	9,322 K.W.
1899.—37	„	„	8,974 „
1900.—39	„	„	8,209 „
1901.—77	„	„	8,165 „

The increase in the output of polyphase machinery abroad is due in the main to the fact that local conditions gave rise to a demand for it, whereas no demand for this class of machinery existed at home. Moreover, the position of the patents is very ill-defined, and few firms here have thought it worth while to lay themselves open to an infringement action simply to be able to fill a limited number of orders for power distribution and mining work. No doubt this position will soon alter itself, though as regards the use of polyphase machinery in ordinary factory work the want of flexibility of speed control militates against its application in this direction, where minute speed regulation appears to be of increasing importance.

Standardisation.

Although there certainly has been a very substantial increase in the output of electrical plant during the four years which I have selected for comparison, yet it is probable that the increase would have been still greater if, a few years ago, the engineering interests concerned could have arranged for a certain amount of standardisation. Consider

two firms of equal size and equal manufacturing capacity, one of which, "A," manufactures 50 patterns, and the other, "B," manufactures 100 patterns, both following the modern principle of manufacturing components and afterwards making them up as the orders come in. With an equal stock of tools for turning out these components, and with equal money value of components kept in stock, the firm "A" that works on only 50 patterns will be able to execute an order for any one of these patterns in half the time that the firm "B" will require that has 100 patterns. Then, as the time for executing the order is shortened, so may, for equal dividends paid, the price per article be reduced. The firm "A" therefore manufacturing in less time than "B," turns over its capital in *pro rata* less time than "B," and consequently may be satisfied with a less percentage of profit, and yet pay an equal dividend. Thus quick delivery and low prices go together and help one another to enable the firm "A" to keep its order sheets full.

I imagine that no manufacturing firm exists that would not, if it could, standardise everything it makes, and work to jigs and templates throughout, but in a new industry experiencing a rapid development it is not possible to standardise at an early stage. The process of the survival of the fittest is going on in its usual relentless fashion, and a too early endeavour to standardise would only mean a heavy loss in the abandonment of superseded special tools, or in the remodelling of them to suit the inevitable alteration in pattern. Between these two sets of imperious conditions, on the one hand the urgent necessity for standardising, and on the other hand the danger of doing so too soon, stands the manufacturer, and happy is he whose customers realise the desirability of establishing standards at the earliest practicable point in the history of the development, and so lend a hand in facilitating the manufacture of interchangeable machines.

The Institution of Civil Engineers, with the Institution of Mechanical Engineers, the Institution of Naval Architects, the Iron and Steel Institute, and our own Institution, have now a joint Standardising Committee in full swing, and there is hope that something may be done in the matter, and that consulting engineers and manufacturers may find themselves able to co-operate towards so desirable an end.

Power Schemes.

This subject is wide enough for a long special paper to itself. I cannot do more than briefly refer to it. The scope for constructive business is enormous. The scope for skill to make all the proposed schemes pay well is equally great. I think it may be taken that it will, generally speaking, be no part of the Companies' programmes to compete with the electric light undertakings in their districts, but, on the contrary, to assist the local authorities to obtain Provisional Orders, and to supply them with power in bulk, which they may retail to the inhabitants of their areas.

Traction Work.

Under this heading I include tramways and light railways, but not railways other than light railways. The progress in this branch of the

industry has been marked, but not nearly so rapid as in the other branches previously referred to. The great growth has yet to come, and there are indications that it will be of vast proportions.

The number of firms who in this country make tramway motors is very limited, but the industry is rapidly growing. From the returns which I have received, the output for the year 1901–2 was nearly 40 per cent. in excess of the output for the year 1900–1. Of the total number of cars now running in England, upwards of 80 per cent. of them have motors manufactured in England, and the importation of such machinery is decreasing rapidly.

I will present to you the growth from two points of view, namely, (1) the mileage and number of cars; and (2) the amount of capital invested.

1. *Route Mileage and Number of Cars.*

ROUTE MILEAGE.

1898.—365.
1899.—478 = 31 per cent. increase over 1898.
1900.—576 = 20 „ „ 1899.
1901.—777 = 35 „ „ 1900.
1901 shows an increase of 112 per cent. on 1898.

NUMBER OF CARS.

1898.—2,117.
1899.—2,654 = 22 per cent. increase over 1898.
1900.—3,033 = 14 „ „ 1899.
1901.—3,821 = 26 „ „ 1900.
1901 shows an increase of 73 per cent. on 1898.

2. *Capital Invested* (nearest round numbers).

1898	Companies		9,800,000
1899	Companies	11,800,000	
	Municipalities	1,170,000	
		———	12,970,000
		= 33 per cent. increase over 1898.	
1900	Companies	14,560,000	
	Municipalities	2,750,000	
		———	17,310,000
		= 33 per cent. increase over 1899.	
1901	Companies	19,750,000	
	Municipalities	10,520,000	
		———	30,270,000
		= 75 per cent. increase over 1900.	

1901 shows an advance of 210 per cent. increase over 1898.

It may be of interest here to remind you of two examples of tramway work carried out on novel lines. At Wolverhampton we have the Lorain surface-contact system at work, so far successfully, though a crucial test would be a severe winter with plenty of snow and salt. Then in London we have an extensive conduit system about to get to work.

ELECTRIFICATION OF MAIN LINES OF RAILWAYS.

On the North Eastern Railway a portion of the system is about to be electrified upon a good working scale, and much practical information will no doubt be derived from it later on. It may be regarded as the first attempt in this country to displace existing locomotives. The converted lines will be those running from Newcastle-on-Tyne to Gosforth, with some smaller branches. The main object of the conversion from steam to electricity is to compete with the electric trams, so that the scheme will be laid out as much as possible to look primarily after the passenger traffic.

The employment of electricity for the special purposes of underground railways, or for a new overhead line as in Liverpool, can hardly be looked upon in the same light as the N. E. R. experiment, which is undoubtedly in the direction of displacing steam locomotives from the ordinary main lines of railway in this country. It is, however, a far cry from motor coaches of 160 H.P. each to trains requiring engines to work them capable of developing up to 1,000 H.P., which power can be exerted by some of our main-line engines. The steam locomotive may be doomed, but I cannot help thinking that it will die hard, and I for one shall be very sorry when they are no longer to be seen doing the excellent work which they undoubtedly can do. When, however, this country has been cleared of them, I shall probably not be here to see the result.

A great deal has been said from time to time to the effect that by means of electricity alone and a straight mono-rail track, speeds of 100 miles an hour become possible, and that one reason for this is that the employment of reciprocating parts, as in an ordinary locomotive, prohibits their use for those speeds. In my judgment there is absolutely no foundation for this statement. The only reason why our locomotive engineers have not hitherto enabled us to travel at, say, 100 miles an hour, is that they have never been asked to do so, and if asked, have not had suitable roads with suitable curves and suitable gradients for doing so. If it were decided to run at 100 miles an hour, first of all it would be necessary to lay a straight, or a very nearly straight track built in the very best modern style. They would then probably elect to draw trains of the same length as those proposed to be drawn on the electrical system, namely, one or two long corridor coaches. At 323 r.p.m. a modern locomotive having driving-wheels 6 ft. 6 in. diameter travels at the rate of 75 miles per hour, and this speed is an everyday performance on our main lines. The presence of reciprocating parts does not prohibit such speeds, nor do the engines appear to suffer therefrom. I have it from one of our most eminent locomotive superintendents that the maximum limit might be fixed at 350 r.p.m. Taking, however, the above-named lesser and everyday number of 323 r.p.m., the diameter of the driving-wheels for 100 miles an hour would have to be 8 ft. 8 in., or 11 inches only larger in diameter than the 7 ft. 9 in. wheels, numbers of which are already to be found on our main lines, and doing excellent work. It would be absurd to pretend that a locomotive engine with 8 ft. 8 in. driving-

wheels could be built to take one of our long trains of, say, 14 coaches at anything like 100 miles an hour; but if the train be reduced to the length proposed for electrical propulsion, then a steam locomotive could be built of sufficient power to deal with it, and if the reciprocations of the engine were kept down to the present maximum number per minute, there would be no more difficulty in relation to the reciprocation of the parts than there is now. The conclusion is that it is by no means necessary to fly to electricity for speeds of 100 miles per hour. The steam locomotive will easily give those speeds if they are really wanted on tracks specially laid down for the purpose. The smoothness and steadiness with which one travels at 75 miles an hour, or even at the 86 miles an hour which have been attained on one of our main lines, preclude entirely any apprehension that at a speed of 16 per cent. in excess of 86 miles an hour the smoothness and steadiness would be in any degree inferior upon an ordinary first-class double-rail track laid sufficiently straight for the purpose.

Railway Station General Purposes.

On the London & North Western Railway at Crewe extensive alterations, involving amongst other things the enlargement of the station and junctions, the addition of some 50 miles of sidings, and the erection of a large transhipment goods warehouse, called for some well considered scheme for lighting and working them. For power purposes, instead of enlarging or reconstructing the hydraulic plant, the latter has been abandoned, and electricity alone is used for all purposes. The power-house has a capacity of about 1,000 H.P.

The growing utilisation of electricity for general railway purposes cannot be better shown than by quoting the following instances on the N.E. system: The operation of travelling jib cranes and of capstans at Middlesbrough and West Hartlepool, the equipment of the York carriage works with electric overhead travelling cranes and motor-driven machinery, electric overhead conveyors for goods at York goods warehouse and at Newcastle, electric overhead travelling cranes at the Shildon wagon shops, together with motors for driving punching, shearing, etc., machines; contemplated experiments with the electric lighting of signals at Middlesbrough and Leeds; at York the ticket-printing machines are electrically driven, and at Newcastle the ticket-destroying machine; the new locomotive shops at Darlington are also being equipped with large electric overhead travellers for lifting locomotives, etc., etc.

Railways Points and Signals.

I have included this subject because points and signals require a considerable amount of power to work them with certainty under all conditions, involving the use of electric motors for the purpose. The examples are but few in number, and indeed I am unable to place before you any particulars other than those which Mr. F. W. Webb, of the L. & N. W. Railway, has been good enough to send me. Ten signal cabins at Crewe are now worked or are about to be worked by

electricity. In all they will contain 1,000 levers. One of them will contain 350 levers, the largest signal cabin in the world. The whole are interlocked much in the same way as on the old plan. The use of them does not involve any fresh training of the signalmen. The levers are, in fact, switch levers only, controlling motors or long pull magnets or solenoids, as the case may be, and producing eventually the same results exactly as the old levers produce. How the life of these switches will be affected by the constant sparking remains to be seen, though, if they are made with carbon tips, renewable contacts, and have magnetic blow-outs, it is probable that they will wear well and give but little trouble.

Gas Engines for Driving Dynamos.

I should like to have gone into this subject in considerable detail, but time forbids me to do so. The matter has been recently dealt with by Mr. Humphrey, of the Brunner Mond Company, in a very comprehensive manner, and the present occasion is not at all a suitable one for an attempt to vie with him. One aspect of the case, however, I should like to lay before you. The gas-engine makers of this country, who have turned out thousands of most excellent engines, have for some years past had before them the object lesson of the now almost universal adoption of the inverted vertical steam engine for driving electric generators. The demand arose chiefly from the fact that such engines occupy far less floor space than any other, and that economy of floor space has become of essential importance. Also that it is easy to construct on that system three-cylinder engines with all the advantages of even turning moment which they possess. The gas-engine makers must have realised that eventually large gas engines would run steam engines very hard economically and in other ways, and notwithstanding this they have allowed America to take the lead in producing engines of this type. Any one who has had to do with these engines cannot but appreciate the straightforward simplicity of the three-cylinder arrangement, the ease with which they are started, the excellent governing, and the extremely smooth way in which they run. My firm has had the privilege of engineering a gas-engine generating plant of, eventually, 1,200 H.P. at the Birmingham Small Arms Company's factory, and, being unable to obtain such engines in Great Britain, we were obliged to order them from America. So far, they have given us every satisfaction, excepting on the important point that they were not designed and built in our own country, which I must admit is a truly saddening consideration. There is nothing left for our own makers to do but to copy, unless it be, while following the type lead, to produce something even better than the American engines. Recognising as I do their undoubted ability and skill, I most sincerely hope that we may be within measurable distance of finding that they have accomplished such a highly desirable result.

Measuring Instruments.

Ammeters and voltmeters are the principal measuring instruments

used in the Electrical Industry, and during late years considerable differentiation in the types used for direct-current circuits and alternating-current circuits has taken place. Formerly instruments containing soft iron were largely used for both D.C. and A.C. systems. Now it is customary to employ moving coil instruments in the former, and hot wire or "induction" instruments in the latter. Electrostatic instruments are used in both systems, more especially in high-tension and extra high-tension work. The adoption of moving coil voltmeters on D.C. circuits has much to recommend it, for they are dead beat, quick in action, free from hysteresis errors, and economical as regards power expended in them. The same may be said of moving coil ammeters for currents of moderate strength, but for very large currents the power spent in ammeter shunts becomes a source of expense, inconvenience, and inaccuracy. This arises from the fact that such ammeters require the same P.D. to produce full deflexion whether they are for large or small currents, and as this P.D. is usually about one-twentieth of a volt, the loss in a shunt for 5,000 amperes amounts to a third of a horse-power at full load. This disadvantage is minimised in some cases by using part of a 'bus-bar or feeder as the ammeter shunt. The fact that only comparatively thin wires need be led to the indicating instrument is a great advantage.

For measurements in which high accuracy is necessary the ordinary moving coil ammeter suffers from temperature errors, owing to possible differences in temperatures and in temperature coefficient of the shunt and instrument. Fortunately these errors may be greatly reduced by the use of Campbell's bridge compensating arrangement described in his patent of March, 1901. It is satisfactory to learn that Messrs. Elliott Bros. are introducing this compensation in their "Century" testing sets. Moving coil voltmeters of ordinary ranges have little temperature error, for they can be sufficiently ballasted by series resistance of negligible temperature coefficient.

Hot-wire ammeters for very large currents are open to greater objection, as regards expenditure of power, than moving coil instruments, and in addition to this they are slow in taking up their steady readings even when the current through them is quite constant. This latter defect renders the instrument unsuitable for precise measurements in circuits where the current fluctuates. One means of reducing these defects is to use a series transformer with an unshunted instrument in its secondary circuit.

On high-tension or extra high-tension systems hot-wire voltmeters when direct-connected are very wasteful, owing to a certain current being necessary to cause the deflexion, but here again the consumption of power can be lessened by using step-down transformers.

Electrostatic voltmeters need no step-down transformers or other pressure changing devices, and are extremely economical in power. They have, therefore, come into extensive use in high-pressure stations. An important consideration in connection with alternating-current instruments is their behaviour under different conditions of wave-form, and in this respect hot-wire and "induction" instruments have decided advantages over the soft-iron type. As "induction" instruments take

less power than hot-wire ones, and are usually more robust, they are coming rapidly to the front.

The measurement of power in alternating-current circuits has attracted considerable attention within recent years, and numerous wattmeters have resulted. A large number of instruments has also recently been invented to simplify and expedite the measurement of permeability and hysteresis of iron and steel. The instruments of Drysdale, Searle and Holden are perhaps the most novel of these productions. It is to be hoped that these contrivances will induce users of iron and steel for magnetic purposes to test consignments themselves.

Within my four years period, one instrument has been brought out which, to my mind, is the most interesting that has been devised for many years, and is well worth our attention for a short time. I refer to Mr. Duddell's oscillograph. My admiration of it must be my excuse for bringing it alone before you this evening. Through the courtesy of Mr. Duddell I am able to show you the instrument in operation, and I am very much indebted to Mr. Duddell for the loan of the instrument, and to him and the staff of the Electrical Engineering Department of this University for the trouble which they have taken in setting up the instrument and all the accessories on this occasion.

At the end of the Chairman's address a demonstration was given, showing the capabilities of the Duddell Oscillograph. The experiments were conducted by Mr. Duddell himself.

MANCHESTER LOCAL SECTION.

INAUGURAL ADDRESS OF CHAIRMAN,

By Mr. H. A. Earle, Member.

(*ABSTRACT.*)

(*Address delivered January* 20, 1903.)

It is with pleasure that I avail myself of this opportunity to express my thanks to you, who, as members of the Institution of Electrical Engineers representing the Manchester Section, have paid me the compliment of electing me your Chairman for the present session. It is a compliment which I greatly appreciate. The growing importance of the Manchester Section of the Institution is most opportune at a time when the electrical industry is making rapid and important strides here. As a centre for electrical works in this country, Manchester and district is now the largest and most important. Moreover, Lancashire and the neighbouring county of Yorkshire will, within a comparatively short period, possess electrical generating stations which will be second to none in the country as regards either size or importance. Besides the large municipal supplies in Manchester, Liverpool, and other towns the Lancashire and the Yorkshire Power Companies will shortly start operations; and, notwithstanding the progress of the past, we may confidently anticipate a development in the future which will surpass anything we have witnessed.

With regard to progress in the past, those who have been associated with Electrical Engineering during the last twenty years have witnessed a development and application which the most sanguine could hardly have anticipated. Within the period named the investigations, inventions, and developments which have chiefly contributed to the advancement of the industry are :—

The production and commercial manufacture of the high-voltage incandescent lamp.
The mathematical treatment of the fundamental principles of the electric generator.
The three-wire system.
The series-parallel control for traction work, and
The induction motor.

When mentioning high-voltage lamps, I do not especially refer to the modern lamps of 200 volts and upwards, but to the invention and development of lamps with carbon filaments.

The mathematical treatment of the principles of the dynamo, and the laws which were thereby laid down for its construction, was the most important contribution to the problem of electrical engineering which has been made.

By no means one of the least important points in the evolution of the generator is the universal adoption of carbon brushes, which has so greatly assisted to sparkless running and fixed lead. Various qualities of carbon have been introduced of different resistance and hardness; those of higher resistance and finer grain being found most suitable for high-potential, and those of low resistance and coarser grain for low-potential machines, for, as a rule, no one type of carbon is found equally suitable for a large range or variety of generators.

Incidentally the development of the electrical generator gave a strong impetus to the improvement of the steam engine, and the great accuracy with which electrical measurements can be carried out has been the means of enabling the steam consumption at all loads to be definitely ascertained, and one type of engine to be readily compared with another. This has led to the acquisition of much useful knowledge, and to many improvements in design.

By the adoption of the three-wire system in place of a two-wire circuit, the weight of the copper required to transmit a given power a stated distance, with the same percentage of loss, has been very much reduced, and during the last few years the introduction of incandescent lamps for double the previous voltage has extended the scope of supply on the three-wire system to such an extent that direct-current supply has received a new lease of life, and the competition which at one time existed in this country with the single-phase system has been to a great extent, if not entirely, eliminated.

The series-parallel control for tramway work was one of the great steps which placed electric traction upon a sound commercial footing. By its adoption the units per car-mile were reduced by some 30 per cent., and the maximum current demanded from the station by approximately the same amount, and the great reduction that this represented in the first cost of the generating station and in the cost per car-mile is well known to all engineers.

The induction motor, and the branch of electrical engineering to which it is allied, is the present day development of the alternating-current systems. For many reasons three-phase machines have not been so largely adopted in this country as in some others. The increasing size of stations and the increasing need for placing them further out has, however, given rise to an increasing demand in this country for polyphase currents. But there is no rivalry between the direct and polyphase systems; each has its proper place.

A review, however superficial and short, of past progress may well cause us to ask what degree of perfection have we arrived at, and what may we anticipate for the future? New discoveries and developments generally tend to simplification, and the operations by which a given purpose is effected are generally reduced in number as experience is gained and as the problem dealt with is better understood. If this could in any way be accepted as a law, a brief consideration of the present method of generating light would indeed prove that our procedure is most primitive; for it is evident, even to the most uninitiated, that we obtain our light by an exceedingly roundabout process, and that being so, we cannot expect that it should be highly

efficient or economical. A brief consideration will show the result which is attained.

Taking coal having a calorific value of 14,500 units per pound, and assuming 9 lbs. of steam to be evaporated to 160 lbs. pressure per pound of fuel, the efficiency of the boiler and economiser is, approximately, 72 per cent. An engine taking 13 lbs. of steam per I.H.P. has an efficiency of about 17 per cent., or a combined efficiency with the boiler of approximately 12 per cent.; and, assuming the ratio of the B.H.P. to the indicated power of the engine to be 90 per cent., we find that the ratio of the useful return in B.H.P. to the heat units in the coal is represented by 10·7 per cent. Now 7 per cent. of this figure is lost in the generator, giving an efficiency of E.H.P. coal burned of 10 per cent.

The heat units in the coal have been very inefficiently utilised, but what happens during the operation of converting electrical energy into light? From investigations which have been made in connection with the energy consumed by an incandescent lamp, it has been shown that only a small portion of the total radiation is luminous and capable of affecting the eye as light. Taking this portion as 5 per cent. on the average, we find that of the total heat units in the coal practically the whole are dissipated, and only a remainder of ½ per cent. is converted into the light which it has been our object to produce.

This small result obtained in return for so much coal burned is most unsatisfactory, but how are matters to be bettered, and from whence is improvement to come?

It is evident that for the cheaper production of light by means of the incandescent lamp we must look to improvement in the lamp itself, for it is the most inefficient member of the system with which we have to deal, and since its introduction but little appreciable advance has been made in its efficiency. The production of light by the arc gives a somewhat better return, the ratio of luminous to total radiation being between 5 per cent. and 15 per cent., and the useful return from the heat units in the coal burnt about 1 per cent.

When electrical energy is required for the production of power, owing to the high efficiency of the electric motor, which is between 90 and 95 per cent., according to size, a net return of nearly 10 per cent. is obtained, and in this case the greatest loss takes place in the steam engine.

Besides the study of the efficiency of engines, generators, lamps, and motors, there is in connection with our present generating stations an item amongst the expenses, which all who analyse the published returns well know varies between wide limits, and this is the cost of fuel per unit generated. It might possibly be thought that these large differences were chiefly due to the price per ton which has to be paid. but investigation will show that, apart from any question of price, the actual pounds of fuel burnt per unit sold or generated vary widely at different stations, even though the quality of the coal may not vary greatly and the load factor may be very similar.

The type and size of engine, the class of boiler, the load factor, and the nature of the load, account for a great portion of this difference,

but it seems more than probable that there is, in many instances, a large personal element involved.

Electrical generating stations for lighting and traction have for some time been laid down on lines which have varied but little. There is, however, a great development before us. Large power-stations are about to be erected in various parts of the country to supply power over large areas, and many of the larger towns are building, or are about to build, very large generating stations. All those connected with these undertakings are naturally only too ready to take advantage of any new development, improvement, or invention which may assist to further economies. Are any such opportunities offered to us? Is there any probability of the present reciprocating steam engine being superseded, or can we look for improvement in the incandescent lamp, which, owing to its present low efficiency, is the most unsatisfactory member of our lighting system?

With regard to the former, two types of engines are now forcing themselves upon our notice. They are the steam turbine and the gas engine.

The steam turbine, in the able hands of its inventor, is now reaching a degree of perfection when it can no longer be neglected, for it is not only becoming the rival of, but for many purposes is actually threatening to supersede, the reciprocating engine. An engine in which the moving parts are reduced to the minimum cannot fail to be attractive, and in the turbine, valves, eccentrics, and reciprocating parts are entirely absent. The economies which have been effected in the steam consumption of the turbine are due to a variety of improvements, but to a large extent to the advances which have been made in connection with it when running condensing. The design of the turbine constitutes it a multiple-expansion engine, in which the steam can be expanded one hundred- or even two hundred-fold, as compared with eight- to sixteen-fold in the compound or triple-expansion reciprocating engine. To this exceptional ratio of expansion the economy of the engine is to a large extent due, and as the expansion extends over nearly the whole range between the boiler pressure and that in the condenser, the effect of a good vacuum is most important, and for every additional inch of vacuum above 25 to 26 a saving of approximately 5 per cent. is obtained. In the turbine there is no initial condensation, and therefore greater gain by a good vacuum than in the reciprocating engine. In the latter type of engine a function of good vacuum is a corresponding increase of size of the engine so as to cope with the greater volume of steam, but this is not so in the turbine, and on this account, in the turbine, steam can be expanded to a limit which mechanical considerations render impermissible in the reciprocating engine. In the average reciprocating engine much loss is caused year in and year out by leaky slide valves, and great loss is due to alternate contact of the inside of the cylinder walls with cold exhaust and hot steam; but in turbines, as the flow is always in one direction, there are no periodic fluctuations, and therefore none of the above loss. Besides the excellent results as regards steam consumption in the turbine, it claims other advantages of considerable importance. The first cost of the combined plant is

appreciably reduced, the necessary buildings are much smaller, and the foundations inexpensive. No internal lubrication is necessary—the saving on this account is considerable—and the condensed steam can be returned to the boiler uncontaminated by oil, and without the necessity for oil filters.

The second type of engine, viz., that using gas as the motive power, has comparatively recently, owing to the greatly increased size in which it can now be built, and the production by various processes of cheap gas, won for itself a very high position, and one which is fully justified by its performances, and it has established its claim as a competitor of the best and largest steam engines.

The four strokes per cycle single-acting engine is that which in the past has been commercially the most successful, but as the demand for engines of larger and larger size has arisen, the disadvantage of only utilising one stroke in every four for the generation of power, and the necessity for two or even four cylinders for engines of no very great power is tending rather to the adoption of one impulse per revolution, or even one impulse per stroke.

Records exist in great quantity of gas engine performances, both for the older and more modern types, but it is unfortunate that confusion should be so often caused in their study by the employment of units based on different temperature scales and weights. Thermal efficiencies are also calculated in two different manners, based either upon the higher or the lower value of the gas, and by the existence of three determinations of calorific value, and two methods of calculating the thermal efficiency, the performance of an engine may be presented to us in any of six ways. This in an outrage upon our time and patience, more especially when one has frequently to search through a whole book or paper to discover the units upon which the results are based.

So long as gas engines were run upon town gas their field of operations was limited to comparatively small powers. But as the size of engines increases, the efficiency of the steam engine rapidly improves, while for the gas engine it remains more nearly constant; consequently the utilisation of high-priced illuminating gas does not admit of economical working except for small powers. To enable gas engines to compete with steam for the generation of power on a large scale, a cheap and reliable gas is essential, and for many years inventors have been working on this most interesting and important problem. Apart from the question of producers, designed especially for the manufacture of power gas, there are sources of supply which, when available and turned to account, yield exceedingly valuable results, and the utilisation of the gases from blast furnaces and coke ovens—the great portion of which has up to the present been allowed to go to waste—is a problem of the very greatest importance.

Excluding illuminating gas, which is too expensive for use in large gas engines, natural gas, blast furnace and coke oven gases, which are only occasionally available, three kinds of gas remain, which are named respectively producer, water, and power gas.

Producer gas is generated by forcing a current of air through

glowing coal. Water gas is produced by passing steam through fuel which has been raised to incandescence by first passing a current of air through it. The production of power gas is a combination of the two processes, in which steam and air are admitted simultaneously, and though the resultant gas is poorer in quality than water gas it is richer than producer gas, and the process has the great advantage of being a continuous one.

Power gas was, during the early years of its manufacture, made from anthracite or coke, and excellent results have been obtained, by which a horse-power-hour is produced for about 1 lb. of coal, but lately a process has been designed which enables the cheapest bituminous coal and slack to be used and at the same time the ammonia to be recovered as sulphate of ammonia. It is hardly to be wondered at that this great advance in the economical production of gas has brought the question of the utilisation of gas engines for the production of power on a large scale into great prominence.

The relative working costs of gas- and steam-driven plants are dependent upon the quality and cost of fuel which the type of producer requires, and the cost of coal for the steam plant.

Briefly comparing a 400-H.P. steam plant with a gas plant of equal power (the latter utilising gas manufactured from anthracite), we find that a 400-H.P. compound steam engine, condensing, including boilers, boiler-house and chimney, would involve a capital outlay of approximately £5,900. When working this plant for 3,000 hours per annum, and taking the cost of coal at 10s. per ton, the total yearly cost, including depreciation and interest on capital, would be £1,575. This gives a cost per H.P. per hour of 0·325 pence.

Considering this against a gas engine, producer, and building, the total capital outlay for the plant for the utilisation of anthracite would be £4,500, and, taking the anthracite at 23s. per ton, the working expenses would be £1,475, or 0·3 pence per H.P. hour.

These figures relate to a plant in which expensive fuel is used in the producer, and when considering the cost per H.P.-hour it must be borne in mind that it is assumed the plants are running for ten hours per day on full load.

With respect to producers for the production of gas from bituminous slack; the cheaper fuel gives results which show a considerable economy when gas plants of even 500 H.P. are compared with steam, and without taking into account the question of ammonia recovery. But when the power rises to 3,000 H.P., or thereabouts, and it becomes economically advantageous to recover the ammonia, the value of this bye-product reduces the nett cost of the gas to such a figure that, with coal delivered at 8s. a ton, the nett cost of fuel does not exceed one-twentieth of a penny per H.P.-hour. Such a result is one which points to the certainty of the adoption of the gas engine for all large power plants.

Besides the reduction of coal consumption by the aid of rotary steam engines or of gas engines, there is the possibility of reducing the cost per unit by improving the load factor. A large generating station, with a tramway and power load may have a factor approxi-

mating to 20 per cent. If this could be increased to 50 per cent., costs would fall by practically one-half. Storage batteries are the only known means at our disposal for effecting an immediate change of this magnitude; large first-cost and the maintenance charges alone stand in the way of their immediate adoption upon an enormous scale. We are, in fact, waiting for the ideal storage battery. The destruction of storage batteries is due to the continual expansion and contraction. A cell with a life greatly in excess of anything yet produced is no impossibility. Whether the iron, nickel-oxide battery, of which we have heard, is to solve the problem of long life, or whether iron is to replace lead, I do not know; but iron is the cheapest of metals, and, weight for weight, should yield a watt-hour output about the same as zinc, and many times greater than lead, and if the initial difficulties have been overcome this new departure in batteries will be of the first importance. But it is well to note that a great length of life is not all that is required, the first cost being as important a factor, for the interest on any additional outlay must be charged against any saving effected in yearly depreciation; and, if the cost of the battery is increased, in order that the yearly charges shall remain constant, the life must increase as the square of the cost. Apart, however, from the use of batteries merely for the purpose of storage, there is an immense field for their employment as regulators in large power-stations.

Touching upon the question of the supply of electricity in bulk for power and other purposes, this is a subject upon which a war of argument has been waged, and the financial success of such undertakings has been questioned. We may, however, leave this great question to decide itself upon its merits, for several of the power companies have already started operations. The power companies have been excluded from giving customers a supply within certain town areas, with the object of protecting the municipalities from competition, and although the towns are at liberty to take a supply, or give permission to supply, they as a rule do not at present look with favour upon these gentlemen with roving commissions. Still, the effect of the companies, carrying on operations outside their gates, will be felt, for low charges for power will tend to attract small manufacturing firms to districts where rates are low and land is cheap.

I have given some consideration to the question of the supply of energy by power companies for the purpose of lighting small districts, and have also worked out the savings that would be effected and the extra expenses that would be entailed by putting in batteries of sufficient size to increase the load factors from 9 per cent. to 20 per cent., and the result of my investigations goes to show that the prices which would have to be charged compare most favourably with those charged by small companies having outputs similar to those I have assumed. But the true object of the power companies is the supply of energy for *power*, and for success upon a large scale all costs must be cut down to the lowest possible figure. Hence such companies are bound to give, as I have said before, consideration to the steam turbine, the gas engine, etc. The cost of the electric *light* could also be reduced by improvements in the lamp itself. At the present time the efficiency

of the lamp is such that the hourly cost of current greatly exceeds the hourly cost of the lamp, for, taking the cost of a 60-watt lamp at 1s. and its useful life at 1,000 hours, we find that at 4d. per unit the hourly cost of current amounts to twenty times the hourly cost of the lamp. This great difference between the two charges indicates that the lamp should, on commercial considerations, be called upon to do more work with a smaller expenditure of power, even if thereby its life were shortened. Many attempts have, of course, been made to produce a substance capable of being run at a higher temperature than carbon, and there is no reason why we should not look forward to an efficiency which would at any rate halve, or even quarter, the present cost of lighting. The mercury lamp may indicate the type of the future, but at present the quality of its light is not such as would recommend its adoption.

And now to what extent are our home firms in a position to take advantage of home and colonial demand. I am convinced that we are in every way able to hold our own in the competition, but we must not fall into the dangerous error of hiding from ourselves the many excellent features in the machinery of our foreign rivals. Looking back upon the steady and continual progress which has been made, and considering the great opportunities that are still open for improvements in the various branches of electrical engineering, the many applications of electricity which are only yet partially developed, and its great future in connection with power-distribution and electro-chemistry, one cannot help feeling with some degree of confidence that the progress of the present century will equal, if not surpass, that of the last.

LEEDS LOCAL SECTION.

INAUGURAL ADDRESS OF CHAIRMAN,

By Mr. HAROLD DICKINSON, Member.

(*ABSTRACT.*)

(*Address delivered February 19th, 1903.*)

In electing me your chairman for the first year of the existence of the Leeds Section of the Institution of Electrical Engineers, you have conferred on me an honour of which I am justly proud, and for which I thank you.

In the earlier part of my address I propose briefly to rehearse the objects and advantages of the Institution, and with regard to the rest of my remarks I have decided, after some thought, to leave all technical matter to be dealt with in papers specially devoted to specific subjects and to seek to lay before you the commercial and educational problems with which, sooner or later, we shall have to deal. This I do in no dogmatic spirit, but rather in the hope that, by pointing out what I conceive to be imperial issues, an avenue is opened for their consideration and discussion.

The Institution of Electrical Engineers was founded in 1871 under the title of the Society of Telegraph Engineers. It is the oldest and largest Institution of electrical engineers in the world. The Institution has not only grown rapidly in membership, but it has grown in its utility. Local Sections have been formed at home and abroad. *Science Abstracts* have been circulated. Visits have been paid to foreign countries and capitals—to Switzerland in 1899, to Paris in 1900, to Berlin in 1901, and one will be paid to Italy this year, and another to America next year. The Institution has also exercised its influence in regard to Board of Trade Regulations, Factory Acts, and so forth.

I have indicated some of the lines on which the Institution has moved in the past, but there are other duties that will be expected of it in the future. The competition from foreign nations now being experienced in the electrical industry necessitates the careful attention of the Institution to all the problems relating to the progress of the industry, which I hope soon to see having serious consideration, such as questions of the management and conditions of workshops, conditions of labour, education and fiscal conditions. These questions necessarily cannot be discussed by an Institution of this kind with any view to interference, but purely so that the best methods may be brought to the notice of the manufacturers themselves and the representatives of labour, education, and the public at large. Then the Institution may, through its influence with the Colonies, be able to promote the interest of the industry by making known to its Local Sections all that is going on at

home and abroad. Further, the conviction I believe the Colonies have that the electrical industry at home is in a worse state than actually is the case, can easily be corrected through their own Sections.

As to the origin of our Local Section, I may remind you that it was some nineteen years ago that the first efforts were made to form an Electrical Engineering Society in Yorkshire. The movement, however, fell through. Through the instrumentality of our Hon. Sec., Mr. G. R. Blackburn, a local society has now become an accomplished fact by the formation of the Leeds Section.

I should like to point out, now the Section is in existence, that the responsibility of members does not end with the payment of the annual subscription, and that, in order to make the Section a success, it is necessary each member should take a keen interest in the work. I find that the membership of the various Local Sections is as follows: Manchester 445, Leeds 181, Birmingham 180, Glasgow 175, Newcastle 140, Dublin 65. It will be seen, therefore, that with regard to membership, as compared with other Local Sections, we are very well off, and it only remains for the members to put in a little of the enthusiasm they instil into their profession to make this Section one of which the parent Institution and the other sections will be proud.

Before coming to the immediate subject of the second part of my address, I should like to call your attention to the phenomenal progress which the industry in which we are all interested has made during the last thirty years. In the early days Telegraphy was its mainstay, then came Telephony, then Lighting, and then Traction, in which there is now £60,000,000 of capital invested. In regard to lighting, the enlargement of the business has enabled the cost of production to be reduced, and we may anticipate further reductions in the near future by reason of the improvement in the load-factors due to a more diversified type of user. The price at which electrical energy can even now be sold is such as to place it within the reach of all classes.

One great reason why there is not a much greater increase is, I think, the initial cost of wiring. Any steps taken to reduce this cost must tend to the benefit of the business and lead to an increased use of electric light as an illuminant.

We have all recently heard a great deal about the various power schemes that have been formulated throughout the country. It seems to have been assumed by many people that because a scheme is designated a power scheme it possesses some merit which will enable power to be supplied at very low cost, but the principles which go towards the production of energy at low cost are apparently forgotten. Unless a power scheme has a good load factor it seems hopeless to expect low costs, yet in many of these cases the areas are immense and the districts very scattered, which involve very heavy distribution costs. I do not wish to say one word to discourage any scheme which may benefit the industry, but I consider that, before the public are invited to subscribe money for the development of some of the schemes proposed, the facts should be very carefully weighed in the light of our present experience of the factors which govern the cheap production of power, for, if a number of these schemes are unsuccess-

ful, it will tend to shake the confidence of investors and thereby cause a serious check to the industry.

What has already been stated shows very briefly how the industry has advanced, and its continued advancement may be forecast when we consider the number of new schemes for the future.

Our Position to meet Competition.

But, gentlemen, the consideration we have just given to the development and prospects of the industry at once suggests the question, "To what extent are we equipped for meeting the future, electrically and generally?"

It will be admitted that commerce plays a very important part in deciding the position that a country occupies among the nations of the world, and, true as this is of our day, how much more so is it of the future? We must all appreciate this, and it is therefore incumbent on us as a nation to study commerce and all things that tend to enlarge and foster it. There are, of course, many avenues through which we may study it, and this brings me to the crux of my address, and, conscious as I am of my own limitations, I only deal with the subject because I feel that the position of commerce generally, and the electrical industry in particular, in the United Kingdom is not on the sound basis we should all like to see it. The question before us is of vital importance both to the producer and the user of electrical apparatus. The magnitude of the problem is obvious, and I fully appreciate the vast knowledge essential in order to arrive at a correct decision as well as my own lack of that wide experience necessary for the formation of any reliable opinion. But as to the *lines* of the question I am fully convinced, and I content myself rather with suggesting those lines than with the expression of any very definite opinion thereon. So serious is this problem, not only to our industry, but to commerce itself, that I am sure every one who has the welfare of the empire at heart will feel that, whatever one's limitations, one is quite justified in raising one's humble voice to swell the chorus now being raised that serious, studious, and practical application may be given to the issue before us.

There can be little doubt that, till quite recently, British capitalists and manufacturers have dozed. The commercial habits of their early days have been allowed to be the only habits that could attach to business life. Precedent has been followed instead of new precedents being established. Indeed, I suggest that precedent should be, comparatively speaking, a dead word, for a new precedent is scarcely established before the environment of commercial life renders it antiquated. A perpetual study should be given to the ever-changing conditions of commerce, and business should be continuously adjusted to these conditions. Fortunately, the commercial instincts of our day have responded to the uneasiness occasioned by the wonderful advances of our commercial rivals, and the last few years have been spent in good work whose fruit will assuredly be seen.

But it will be obvious that the question "To what extent are we

equipped for meeting the future?" is not merely a question of our day. It is one for all time. Each generation must ask itself that question. Having asked it for our own day, let us proceed to examine it. It seems to me the question must be examined under at least the following four heads: (*a*) Foresight, (*b*) Management, (*c*) Education, (*d*) Fiscal Conditions.

Foresight.—The consideration of foresight may be dismissed in a few words. One instance of the want of foresight of our electrical manufacturers may be seen in their neglect to lay themselves out some years ago to meet the demand for the larger units required for central stations, with the result that so many of the largest sets were supplied by foreign firms. It is always easy to speak after events have passed, but that this demand would arise for larger units was so absolutely certain and so perfectly obvious to those who considered the subject that it is astonishing to me that manufacturers should have allowed themselves to be in the invidious position of seeing orders, which ought to have been theirs, going out of the country.

In this connection I appeal to our moneyed classes to realise more fully the dignity of commerce, to sink their money in ways that, if they do not yield immediate prospects, will certainly show handsome future returns. It is to these men we must look for assistance in the opening up of new markets. It is of them we demand that instead of buying up landed estates that yield but little either now or hereafter, they will invest in that which will ultimately provide them an ever-increasing yield and the nation with a hard-working, intelligent, commercial community.

Management.—In considering this question we must do so in comparison with our competitors abroad. In the electrical industry it is, I say, a serious reflection on our manufacturers of electrical plant that the bulk of the orders for the largest schemes have gone to foreign firms, or at any rate to firms of foreign origin. It gives much food for reflection that to-day the purely English electrical firms, with perhaps but one exception, are not in a position to take one of these large contracts in competition with the large American or Continental firms, for the simple reason that the English companies are too small. I do not say that they could not execute the work from an engineering point of view. I think they could, and certainly as well as (possibly better than) the foreign firms, but I say that for financial reasons such contracts are prohibitive to them at present, the risk with their comparatively small capital being too great unless they could get the contracts at their own prices, which must be liberal. They dare not take such a competitive contract, for the reason that it would mean that their works would be run almost entirely for one job, and in case of any miscalculation they might be put into a very awkward position. It is evident that our manufacturers are now progressing, but I am afraid it must be admitted that it is not so much due to their desire to obtain the best results, but rather to sheer necessity.

With regard to the question of labour, I think our manufacturers must, in their own interests, and in the larger interests of the nation, study this question seriously. I know that blame is laid at the door of

the working man for restricted output, and often do we hear the men criticised in this respect; but is it just? Is the blame all on one side? I say emphatically, No. I believe the cause of restricted output is due to the system of payments generally in vogue. If you wish to get the greatest output you must pay for it. This, it seems to me, can only be done by paying on a liberal scale on the bonus or premium system, or some other system which will give an inducement to exert best endeavours. If this practice were more general in England we should see more of the close attention and the steady and consistent application to the work on hand that is so marked in up-to-date workshops. The greater security the manufacturer can show for the future maintenance of the higher wage earning facility this scheme affords, the greater will be the chance of the system becoming general, which will be to the permanent advantage both of the manufacturer and the artisan. It must be understood, of course, that in advocating this attempt to obtain increased output, I am not advocating in any way any lowering of the standard of quality of goods produced.

In addition to this, the workman should be induced by every means to use his brains to suggest any new process or tool to facilitate greater output, and to do this it will be necessary to compensate him for his skill where it is found to be beneficial. I have often heard it said that the British working man has no brains. I do not believe it, and I sympathise with what he has said, by his actions, that he is not prepared to give the manufacturers "something for nothing." If he has brains he is capable of being influenced, and it is the duty of the manufacturer to see that he is properly influenced, and this can be most readily done by making it worth his while to try.

The last point I would mention under this heading is that of advertisement. There can be no doubt that orders have gone to at least one of our rivals because of what I will term his arts in advertising. These are not confined to the orthodox announcement in a trade journal, nor to the apparently inspired leaderettes in the daily press and the monthly magazine, but to his assiduous and ofttimes daring approach to possible users by careful and attractively penned letters, and by the ingenious ways—I was going to say bluff—of his representatives. I think we underdo advertisement as much as this particular rival overdoes it, and suggest our manufacturers give more heed to the subject. The moral I wish to point is that the British manufacturer has hitherto been too modest in advertising, and that the time has arrived when the excellence of his productions and his stereotyped form of trade journal announcement shall not be his only means of communicating his existence to the world. I suggest he give some study to the subject of judicious advertisement and seize every opportunity of acquainting possible buyers and the general public, through the medium of the daily press as well as the trade journals, with what he has done and is doing.

Education.—On this subject let me request you all to read anew Professor Perry's inaugural address of 1900. Whilst I emphatically disagree (not from any strained patriotism, but from reading and observation) with the Professor's inference that British electrical

engineers are behind those of America or the Continent in skill or aptitude, the re-perusal of his brilliant and practical "straight talk" is a tonic we should all take periodically. But, as I pointed out in my letter which appeared in the *Electrical Times* of the 20th December, 1900, if the British engineers' theory is faulty and incomplete, the methods adopted in our colleges and institutions must be faulty and incomplete. Since then there has been a practical advance in general commercial education, but the curricula followed are mainly on foreign lines. I assert that we should be in the van of technical educational progress, not followers merely. Those in charge of this important department of our national activities should certainly have associated with them representatives of every branch of engineering, and they should formulate a British curriculum. The value of constant and intimate association between technical schools and manufacturers cannot be overrated. The need for such co-operation is growing, and, as the benefits of the secondary schools go to the manufacturers, I am quite sure co-operation will result in manufacturers helping the schools with funds and plant.

Fiscal Conditions.—The question of our fiscal conditions is one that, as I have already stated, I am not prepared to dogmatise upon. On the one hand, keen competition and the necessity for tackling big jobs, which leads to amalgamation and combination, often ends in trust abuses, whilst, on the other, a mote of necessary protection may lead to a beam of abuse. Yet there is no doubt the tariffs of foreign nations are becoming vexatious and require much study.

As regards our specific business, I have been thinking the matter over and have come to the conclusion that there is, in some measure, a degree of excuse for the holding back of our wealthier manufacturers and financiers from erecting big works and laying out extensive plant when there is always the bogey over their heads that empires, which have protected their internal trades by walls of tariffs, have free access to sell over here their surplus at less than cost price, or undertake big jobs at practically cost price, the which keeps their plant fully occupied and has an obvious effect on their trading. The electrical work of to-day and of the future renders big works absolutely essential. Our foreign competitors when erecting such can always feel they definitely command their home markets and can compete on practically equal terms in ours. Have our manufacturers always to endure this increasing restriction abroad and still be weighted by not even having their home markets secured?

I fully appreciate and most earnestly sympathise with our British artisan, and think everything should be done that can be done to elevate and help him. But the question naturally arises: "Is it not possible to cover the increased price of necessaries which might arise if we adopted some measure of protection by the extra work this country would obtain and the higher wages it might pay, and, at the same time, might not other possible grievances be foreseen and foreguarded by systems of bonus or profit sharing?" It may be that the welding together of the British Empire will largely reduce the poignancy of the question of free trade as it stands to-day, but that is a matter of very

considerable time, involving as it does the fiscal policies of young nations.

Under this head, too, the question arises as to whether our Government gives sufficient consideration to trade questions. We are agreed that we do not want too much Government interference. But I am heartily in accord with the movement now being mooted by eight Chambers of Commerce that the time has arrived when we should have a Minister of Commerce, whose duties should be initiative rather than administrative, whose time should be absorbed in finding openings for trade and advising on all matters concerning the conditions of trade abroad. In this direction invaluable work is being done by the Commercial Intelligence Department of the Board of Trade. But, good as is the work of this department, it only goes to prove the necessity of its having a separate existence. The administrative work of the Board of Trade is vast. What we need is some one who is free to initiate and who will be responsible for any neglect in this direction.

I hope I have made it quite clear that I advance neither the doctrine of free trade nor that of protection. What I do assert is that the question is a grave one, immediately demanding further study, and I plead that pressure be brought to bear on those in high places at once to collect and study the data necessary for arriving at a conclusion to lay before the nation.

In conclusion, let me assure you I am no pessimist. If we have not kept abreast of the times it has been for reasons that would perhaps largely have led to others becoming lax had they been in our place. The British manufacturer is a man with a level head and a lion's pluck, and he has awakened from his slumbers. The British workman is a good fellow. I tell you I have been all over the British Isles on the one hand, and on the other hand I have visited many big works in the principal towns of the United States, Germany, Austria, and elsewhere, and, whilst allowing for the disadvantages of flying visits, I did not go with my eyes shut, and I tell you that for solid good work we are unrivalled. To this good property we are soon to add the advantages of our new interest in Technical Education and the like, and if only employers will devote themselves to the earnest, strenuous study of inter-trade problems and can see their way to bring men to be paid on results—and in no mean spirit—the prospects of the old country in the future are as great as ever they have been in the past.

NEWCASTLE LOCAL SECTION.

EXPERIMENTS ON SYNCHRONOUS CONVERTERS.

By W. M. THORNTON, D.Sc., Member.

(*Paper read at Meeting of Section, December 1, 1902.*)

§ 1. The growth of large schemes for the electrical transmission of energy by high-tension alternating currents is probably the most remarkable feature in modern industrial development. The success of these schemes depends mainly on unfailing regularity of supply, and this again on the stability of the electromagnetic system of generators, line, and motors under all loads. Those responsible for these schemes make very cautious experiments, the cost of misadventure is too great, and the machines themselves are rarely available under all the conditions necessary for a complete study of their behaviour. I had the pleasure of making some observations of wave-forms on the synchronous motor system of the Wallsend scheme, and these suggested that a more detailed research into the working of the two synchronous converters in the college laboratory might add to our knowledge of the complex reactions within the armature of this and allied classes of machinery. The research is entirely experimental. There are so many variables that it is useless to attempt to construct a theory including all of them. Steinmetz and S. P. Thompson have given analyses of the ideal case in which the magnetism is distributed sinusoidally around the circumference of the armature. But though, as will be seen, the generated voltage wave-form at no load closely approximates to a sine curve, this can only be obtained by a magnetic distribution which is not sinusoidal. Kapp has considered the variation of output with relative breadth of pole, showing that within practical limits the output is less for the same armature heating when the poles are broader. In Table I., I quote his figures for two cases, and have calculated corresponding values for the machines used in these experiments, which are not specially-designed

TABLE I.

Type.	Phase displacement.	Sine distribution.	Pole breadth ÷ pole pitch.			
			$\frac{2}{3}$	$\frac{1}{2}$	·61	·88
Single-phase converter	$\cos\phi = 1$	85	88	95	83·6	85·7
	$= ·9$	78	81	88	70·5	75·8
	$= ·8$	69	73	80	62·3	67
	$= ·7$	60	63	70	54·1	57·2
Three-phase converter	$\cos\phi = ·1$	134	138	144	160	160
	$= ·9$	not calculated.	128	137	149	146
	$= ·8$		117	126	132	132

converters. The figures are percentages referred to the same machine working as a direct-current generator for equal armature heating in each case. In the last two columns are the values which might be expected from the two machines used calculated in the same way as Kapp's.

The alternating current, i, which heats the armature to the same degree as the direct, i_1, is $i = \frac{\pi}{\sqrt{q}} i_1$,* the values of q being given in Table VII., and from this relation the latter part of Table I. was obtained. The

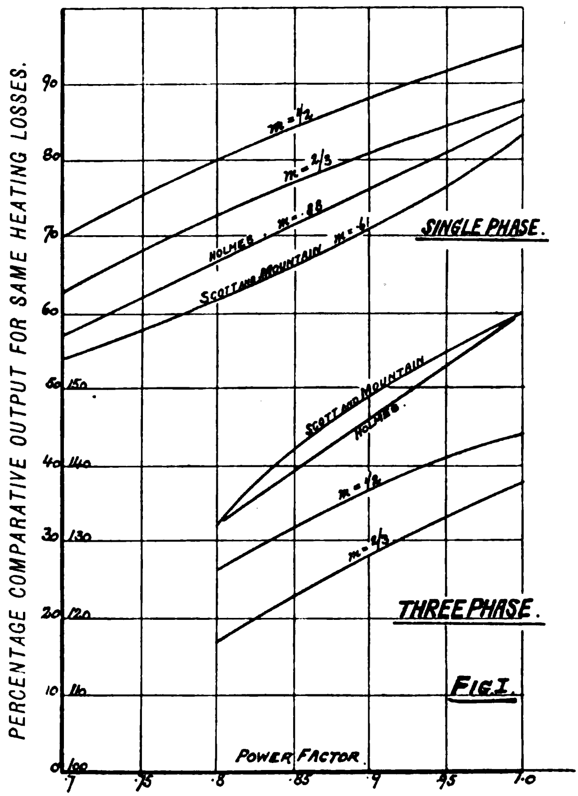


FIG. 1.

results are not total efficiencies. The watts lost in the field, friction, windage, and eddy currents are all omitted, but the results are instructive, as showing the variations in the principal source of loss of efficiency. The comparative values of Table I. are plotted in Fig. 1. Most of the curves show that the relation between power factor and efficiency is not linear, the curvature being generally upwards. The Scott and Mountain single-phase curve is, however, the reverse of this, and in both single and three-phase sets the armature heating is approximately

* Kapp, *Dynamos, Alternators, and Transformers*, p. 476.

in inverse proportion to the power factor. The meaning of the curves drooping towards the low power factor end is in these cases the loss of efficiency due to change of distribution of the current in the armature, and has nothing to do with the effect of the eddy currents in the poles.

§ 2. The object of the experiments was to find how the efficiency of the plant varied with load for all conditions of excitation, to find any

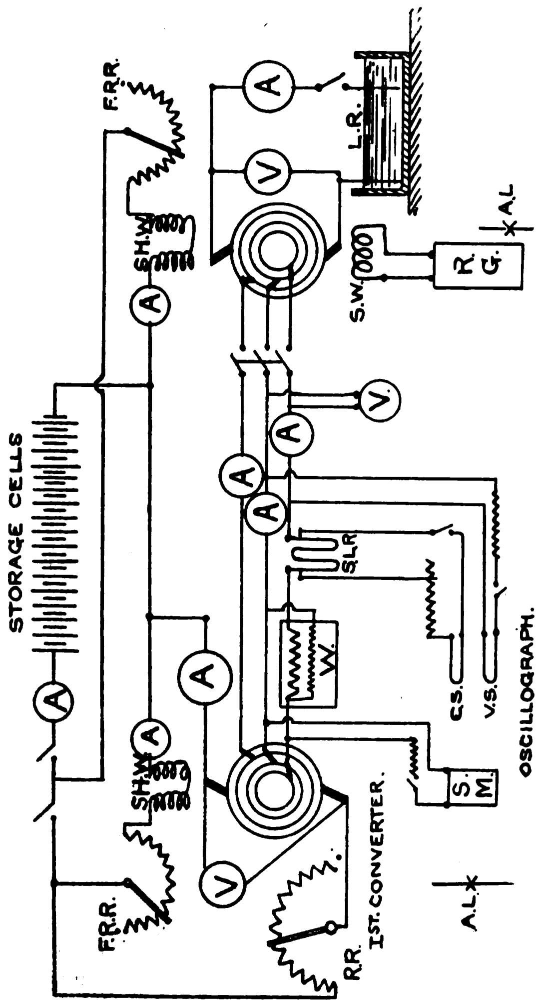


FIG. 2.—A, Ammeters; V, Voltmeters; W, Wattmeter; S H W, Shunt Winding; S W, Series Winding; R R, Regulating Resistance; F R R, Field Regulating Rheostats; R G, Recording Galvanometer; L R, Liquid Resistance; S L R, Standard Low Resistance; C S, Current Strip; V S, Volt Strip; S M, Synchronous Motor; A L, Arc Lamps.

discrepancies between the theoretical and observed losses, and to locate the causes which would give rise to them. At the same time, it was thought that records of the changes of wave shape might throw some light on the nature and magnitude of the armature reactions. The greatest difficulty in synchronous converter working being periodic

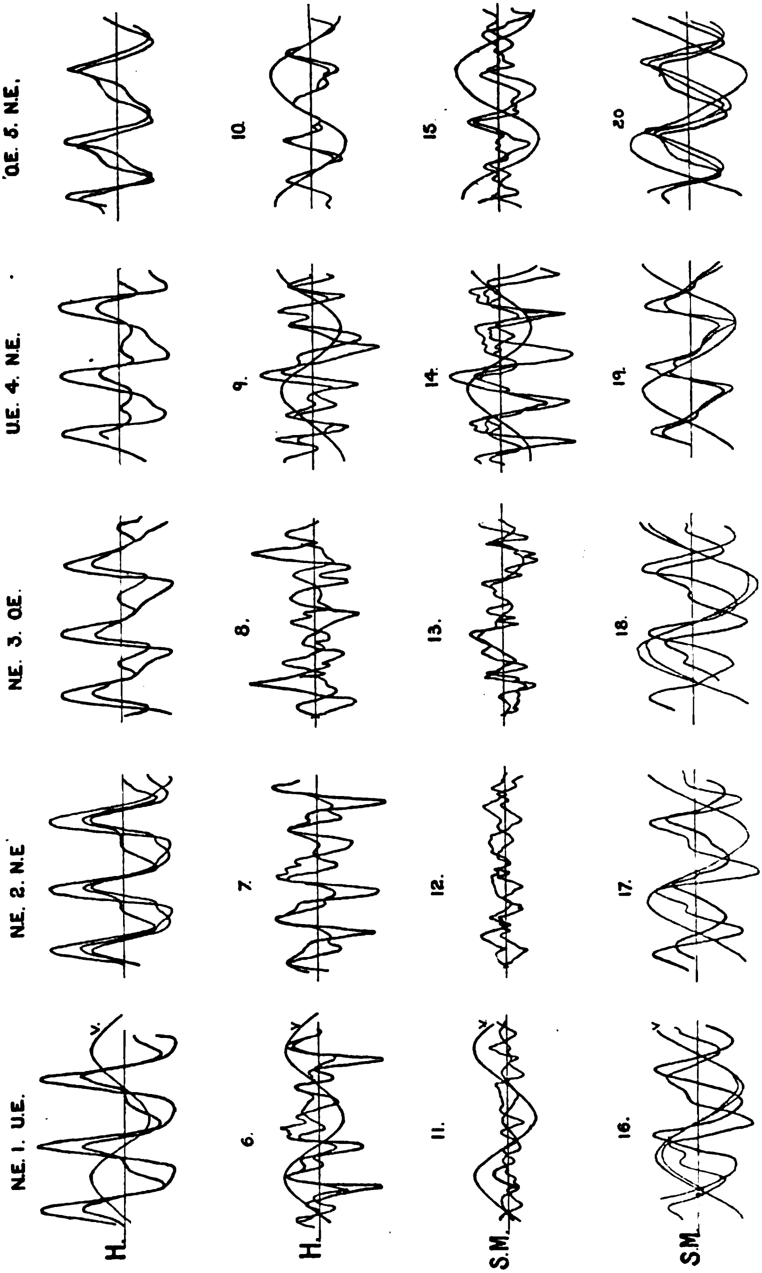


PLATE I.—Oscillations superposed on Magnetic Fields of Converters by Armature Reaction.

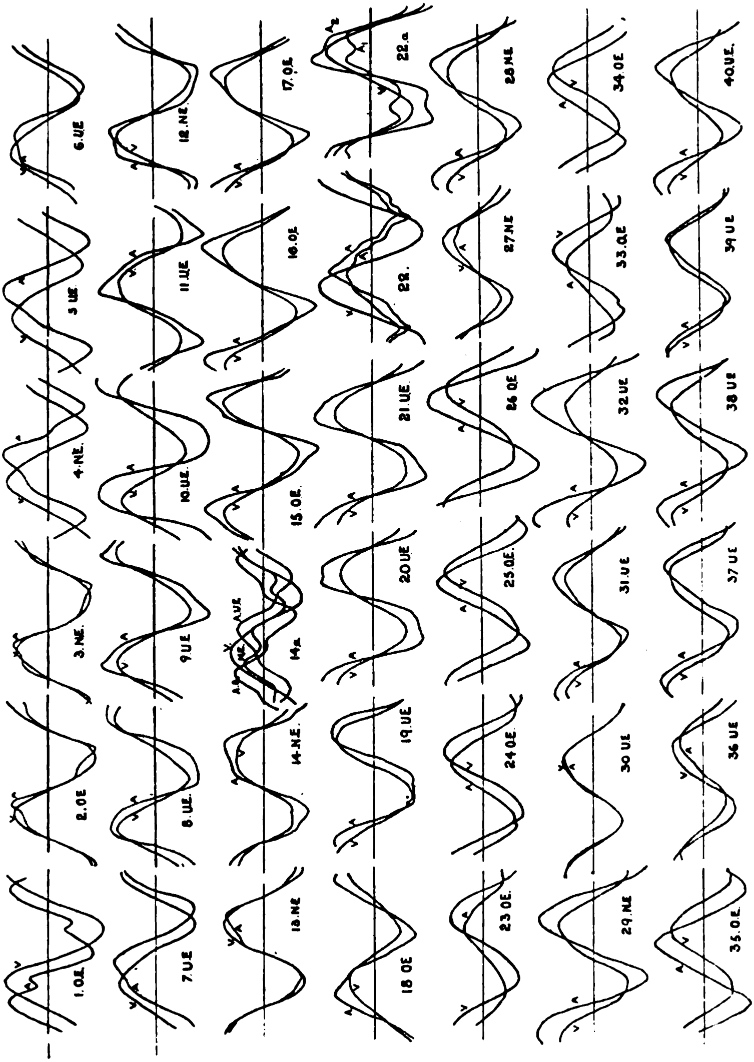


PLATE II. - Change of Wave Form and Phase with Excitation and Load in Synchronous Converters.

fluctuations started from irregular turning moments in the prime mover, the first machine was driven throughout from a set of storage cells. Fifty-two of these were used to drive a 9-kw. bipolar machine (Scott and Mountain), the armature of this being ring-wound and provided with slip-rings, so that single, two, or three-phase current could be taken and supplied to a 5-kw. machine (Holmes), also bipolar and ring-wound in the same way. From the second converter direct current was led through an adjustable liquid resistance. The field of each machine was separately excited from the same cells. A direct-

reading Siemens and Halske wattmeter was inserted in the line in series with a standard low resistance, from the terminals of which connections were made to one strip of a double oscillograph. The other strip was placed in series with a non-inductive resistance across the line terminals in turn. The resistance and capacity of the cables connecting the machines were always negligible. The general arrangement of the connections is shown in Fig. 2. There is, it will be seen, a double conversion of current, and one point of interest brought out by the experiment was that the heating losses of the system could, by varying the excitations, be moved from one machine to the other. The two

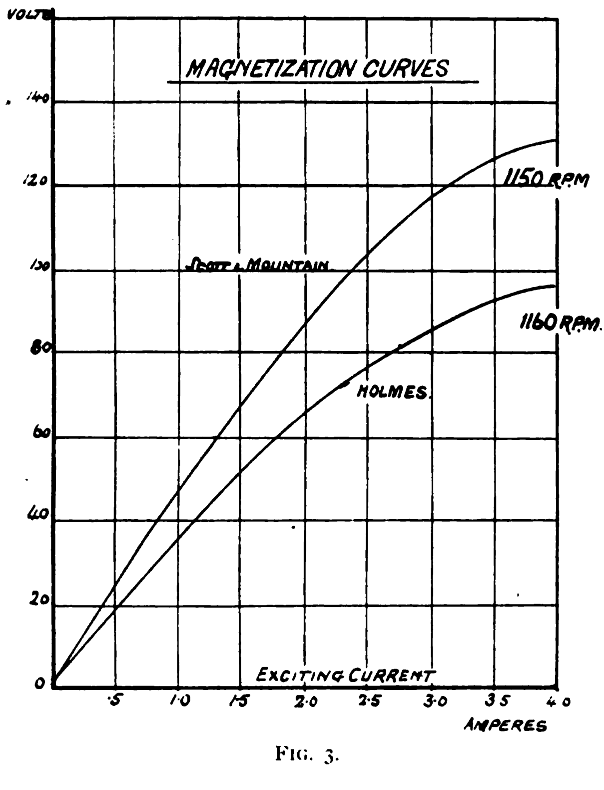


FIG. 3.

machines were run up together from rest coupled by the cables alone, and the load gradually thrown on. Throwing it on suddenly started violent phase swinging in the second converter, which measured in one case 50 deg. difference between the limits of the current wave positions, as shown by Curve 22, Plate II.* The highest frequency possible was 23 alternations a second. The first set of experiments was made to find the relation between total plant efficiency and power factor. The

* Greater swings might have been observed, but whenever the amplitude increased beyond the above limit, the oscillograph synchronous motor came out of step.

observations are given in the following tables, and the magnetisation curves of the machines in Fig. 3. From the latter an estimate of the saturation of the magnetic circuit may be formed. The reluctance of the Scott and Mountain at full excitation is ·00455, and of the Holmes ·00527, and the lengths of the air-gaps are 1·15cm. and 1·06cm. respectively.

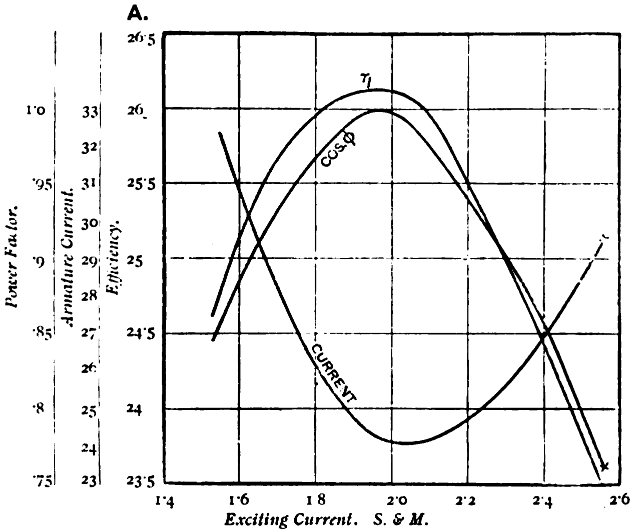


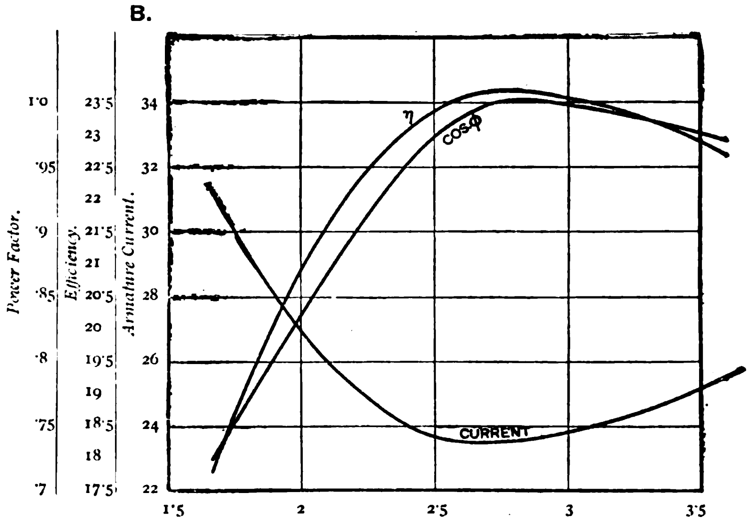
FIG. 4.

TABLE II. (FIG. 4).

Field of first converter varied. Motor field constant. Loss in motor field, 330 watts. Motor output kept as nearly as possible constant.

First converter input.				Motor input.					Motor output.		Efficiency
Volts.	A.	F. C.	Speed.	F. C.	V.	A.	W.	Cos φ	V.	A.	%
70	28·5	1·55	1,000	3·7	45·5	32·3	1,125	·85	72	8·2	24·6
71	27·5	1·62	1,000	3·7	46·5	30	1,250	·90	72·4	8·3	25·3
72	26·3	1·70	990	3·7	47·0	28·2	1,225	·93	72·4	8·3	25·8
74	25	1·85	980	3·7	48·0	25·3	1,174	·97	72·4	8·2	26·0
75	24	1·98	950	3·7	48·2	24·1	1,165	·99	72	8·1	26·1
75·2	23·5	2·10	930	3·7	48·5	24·0	1,134	·97	70·6	8·2	26·1
74·5	24	2·12	900	3·7	47·8	25·25	1,150	·95	70	8·0	25·6
76	23	2·34	920	3·7	48·1	25·9	1,100	·89	69	8·0	24·7
76	22·5	2·55	930	3·7	48·0	29·3	1,074	·76	67	7·8	23·5

It will be seen that the maximum efficiency is reached a little before the minimum current.



Exciting Current. Holmes.

FIG. 5.

TABLE III. (FIG. 5).

Field of first converter constant. Motor field varied. Loss in first converter field, 116 watts. With the same input as in Table I., the output and efficiency are less.

First converter input.				Motor input.					Motor output.		Efficiency.
Volts.	A.	F. C.	Speed.	F. C.	V.	A.	W.	Cos φ	V.	A.	%
73	26·1	2	980	3·7	48·2	25·8	1,210	·97	72	7·4	22·6
74	25·8	2	990	3·29	48·5	24·5	1,180	·99	71·6	7·4	23·2
74·1	25·4	2	1,100	2·98	48·5	24	1,150	·99	70·6	7·3	23·6
74·2	25·2	2	1,010	2·7	48	23·5	1,129	1·0	69·7	7·1	22·9
75	25	2	1,030	2·5	48	23·7	1,104	·97	68·2	7·0	23·5
75·1	24·4	2	1,040	2·3	47·8	24·5	1,079	·92	67	7·0	22·5
75·1	24·4	2	1,060	2·17	47·2	25·3	1,069	·89	65·8	6·9	21·9
75·3	24·2	2	1,070	2·03	47	27	1,060	·83	64	6·7	21·0
75·8	24·1	2	1,080	1·93	46·9	27·8	1,044	·8	63	6·6	20·5
75·8	24·1	2	1,090	1·83	46·2	29	1,034	·77	62	6·3	19·2
75·8	24·1	2	1,090	1·75	46	30·1	1,024	·74	60·8	6·1	18·4
75·8	24·2	2	1,100	1·67	45·5	31·1	1,019	·74	59·8	6·0	17·8

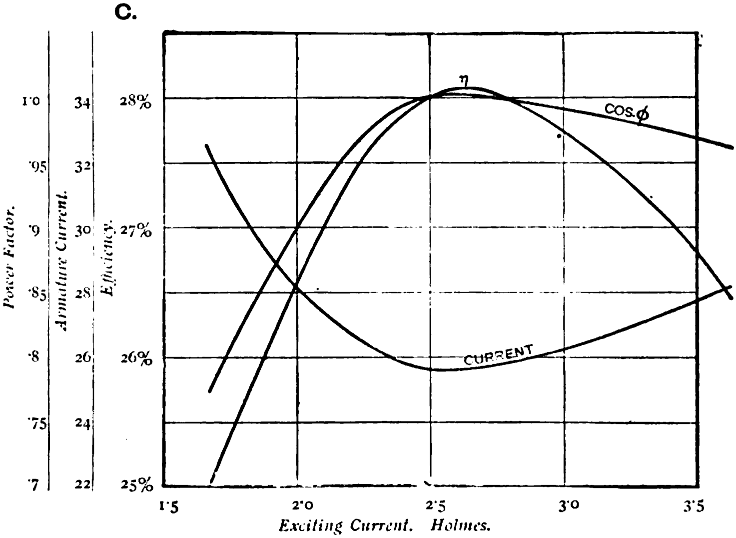


FIG. 6.

TABLE IV. (FIG. 6).

Field of first converter constant. Motor field varied. Current from motor kept constant.

First converter input.				Motor input.					Motor output.		Efficiency.
V.	A.	F. C.	Speed.	F. C.	V.	A.	W.	Cos φ	V.	A.	%
71·4	27·6	2	940	3·6	46·2	28	1,255	·96	69	9·1	26·4
71·4	27	2	950	3·2	46·4	27	1,234	·98	69	9·1	27·4
73	26	2	990	2·66	46·8	25·6	1,189	·99	67·2	9·1	28·0
73·2	25·8	2	1,000	2·28	46	26·2	1,160	·97	64·7	9·1	27·6
74	25·8	2	1,030	2·0	45·2	27·9	1,139	·90	61·5	9·1	26·4
74	25·6	2	1,040	1·8	44·8	30·0	1,109	·82	59·4	9·1	25·8
74	25·9	2	1,060	1·65	43·8	32·1	1,089	·77	57	9·1	24·9

The conclusion to be drawn from the above figures is that, as one would expect, the efficiency is greatest when the power factor is unity, *whichever field is varied,* and it is of interest to note the close relation between power factor and efficiency over a wide range of excitation while the output is maintained constant. Plotting the square of the

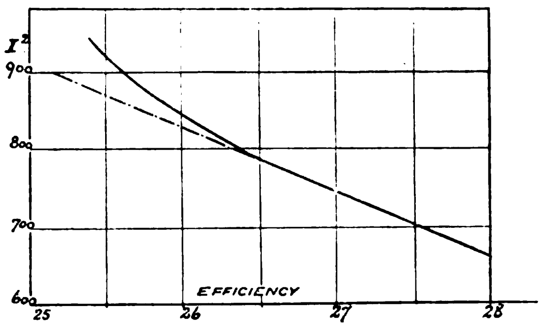


FIG. 7.

continuous armature current against efficiency (Fig. 7), it is found that, except at low magnetisations, they are proportional. At low excitations the effect of the large idle-current component is evident. In order to see whether the higher efficiency was maintained at all loads when the excitation was adjusted for the minimum armature current found above,

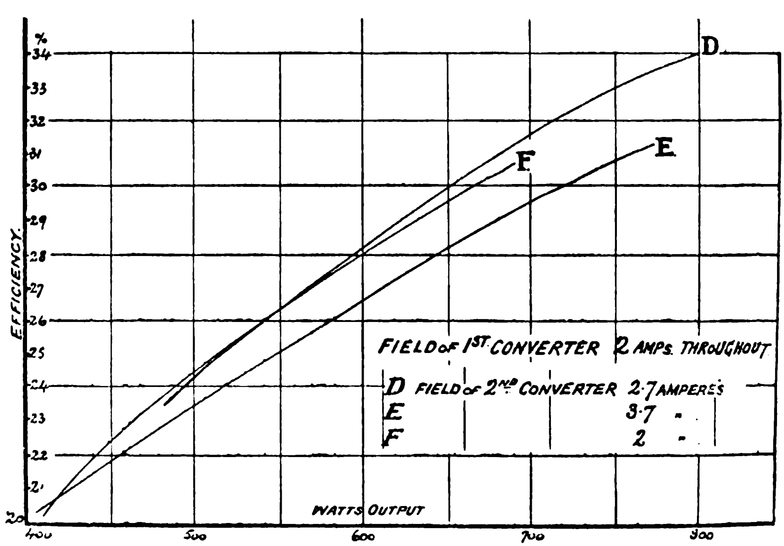


FIG. 8.

three more sets of readings were taken, shown in Fig. 8. The second converter fields were kept constant in each test while the load was varied. The improvement in efficiency obtained at light loads is seen to be maintained at the higher.

§ 3. The next experiment was a variation of the last, the machines being run under all conditions of excitation, and readings being taken of all the variables, including the wave-forms of the line current and voltage. The results with the calculated efficiencies are in Tables V. and VI., and Figs. 9 and 10 are plotted from these. The number of the curves refers to Plate II. The remarkable feature of the curves is their sudden droop at loads which, compared with the ordinary con-

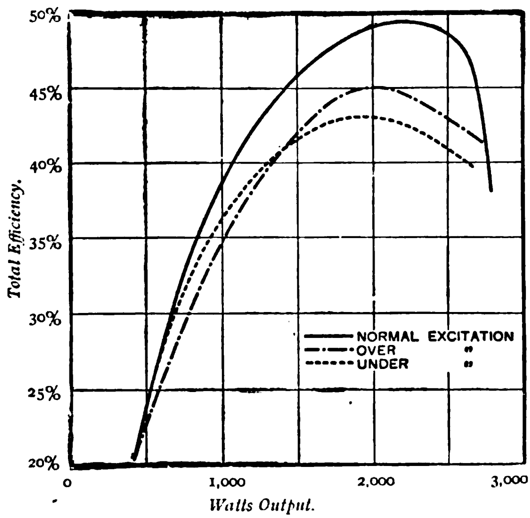


FIG. 9.—Single-Phase Converters.

tinuous-current output, are small. The reason for this appears more clearly when the machines are worked from the main generator, which being driven by a single-cylinder engine has an irregular turning moment. It was almost impossible to reach high loads without the second converter coming out of step, and the only way to obtain them was to over-excite the second machine and so reduce the eddy-current losses and magnetic-current fluctuations and gradually lower the excitation as the load was increased; even then the machine soon worked up a phase swing and came out of step. Fortunately, both armatures have considerable inductance, about ·002 henry, between the slip-rings, single-phase, and there were no ill effects beyond the racing of the first machine. This was the first intimation, as a rule, that the second had broken step, and it was always necessary to keep some one by the main switch of the first machine to break the current before the armature had accelerated to destruction. The advantage of normal excitation is most marked at the higher loads in both Figs. 9 and 10.

Table V. (Fig. 9).

Single-Phase Converters. Variation of Load with excitation constant.

Field Currents: First Machine, 2 Amperes; Second, 1·93. (Second, Under-excited.)

No. of curve.	First Converter input.			Second Converter input.				Second Converter output.			Armature Efficiencies %.		
	Vc	Ac	W	Va	Aa	W	Cos φ	Vc	Ac	W	1st c.	2nd c.	Total.
7	73	31	2260	46·4	44·2	1400	·68	53	13·4	710	62	50·7	28·7
	72·2	40	2890	46·4	51	1976	·83	52	22·7	1180	68·7	59·8	38·3
8	75·5	50·5	4150	43·6	63	2640	·96	55	32·2	1780	69·5	67·5	44
	71	62	4400	40	74	2948	·99	50	39	1950	67	66	42·2
9	80	71	5680	45	84·5	3768	·99	56	44	2494	66·5	65·7	42·0
10	69·2	40	2768	42	48·2	1864	·92	54	22·5	1215	67·4	65	41·0
11	77	81	6240	41·2	96	3944	1·0	52	50	2600	63·2	66	40·5
	Field Currents: First Machine, 2 Amperes; Second, 2·72. (Second, Normal.)												
12	73	36	2630	46·6	40	1840	1·0	68	18·75	1275	70	69·3	43·7
	74	49	3620	46	57	2620	1·0	67	28·75	1925	71·2	73·5	49
13	80·5	61	4900	49·6	70	3464	1·0	72	35·5	2550	70·7	73·6	49
14	72·5	100	7250	36	120	4348	1·0	52	46·5	2880	60	66·4	38
	Field Current: First Machine, 2 Amperes; Second, 3·29. (Second, Over-excited.)												
15	71	40	2840	46	44	2000	1·0	68·7	18·75	1275	70·2	63·75	39·5
	75	49	3660	47	56	2636	1·0	70·5	25·7	1820	71·7	69	45
16	78	72	5616	46·5	84	3856	·99	70	36·5	2560	68·5	69·5	42·5
17	75	80	6000	43·2	95	4008	·98	65	38·5	2500	68	61·3	39·5
	Field Currents: First Machine, 1·6 Amperes; Second, 2·7. (First, Under-excited.)												
	56	40	2240	44	45	1500	·76	56·1	15·7	885	67	59	36·0
18	50	44	2200	32	50	1500	·94	50·5	17·1	865	68·2	57·6	36·0
	Field Currents: First Machine, 3·1 Amperes; Second, 2·7. (First, Over-excited.)												
19	68·5	33	2260	42	47	1480	·75	56·6	15·5	875	65·5	59·7	32·5
	76	45·5	3460	46	57	2400	·92	61	27·5	1675	69·5	70	42·8
20	71	57·5	4080	40·5	70	2860	1·0	52·2	38·5	2010	70	68	44·5
21	77	72	5540	43	88	3880	1·0	55	50	2750	70	71	46·0

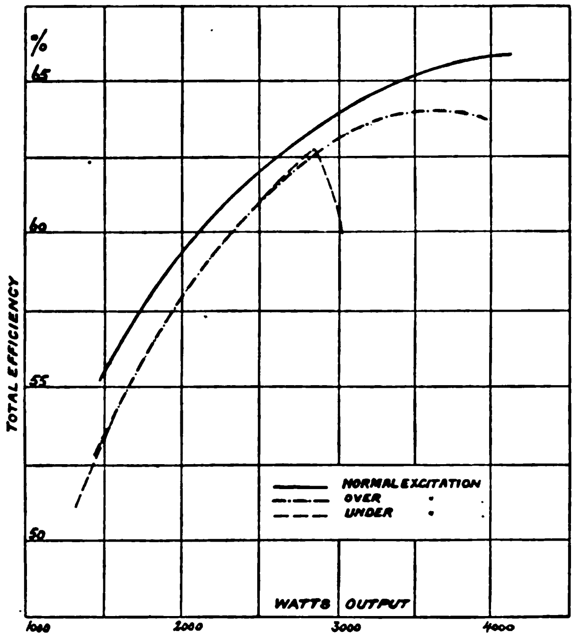


FIG. 10.—Three-Phase Converters.

TABLE VI. (FIG. 10).—*Three-Phase Converters.*

Field Currents: First Converter, 1·9 Amperes; Second, 3·62.
(Second, Over-excited.)

No. of curve.	First Converter input.			Second Converter input.				Second Converter output.			Armature Efficiencies.		
	V_c	A_c	W	V_a	A_a	W	Cos ϕ	V_c	A_c	W	1st c.	2nd c.	Total.
23	75	36	2700	44	23	1794	·75	76	19·8	1500	66·5	83·6	55
	79	44	3470	45·2	33	2480	·74	78	27	2106	71·4	85	60·5
24	85	54·5	4630	50	39	3352	·75	84	34·75	2920	72·5	87·2	63
25	81·5	69	5620	46	53	4122	·75	77	47·5	3660	73·3	88·7	65
26	77	82·5	6350	40·6	66	4650	·75	71	58·5	4160	73·5	89·5	65·5
Field Currents: First Converter, 1·9 Amperes; Second, 2·4. (Second, Slightly Under-excited.)													
27	75	37·5	2815	43·2	27	2472	1·0	74	20	1480	88	60	52·5
	70	46	3220	39	35·3	2480	·98	66	28	1848	77	74·5	57
28	75·5	43·5	4050	42	40	2950	·96	71	35	2485	72·7	84·2	00
	70	67	4690	37·5	52·5	3175	·94	62	47	2914	67·7	92	63
29	78	81	6320	65	65	4210	·91	69	58·5	4030	66·7	96	63·7
Field Currents: First Converter, 1·9 Amperes; Second, 1·95. (Second, Under-excited.)													
30	68	39	2650	37·5	33	2600	1·0	63·5	21·3	1350	98	52	50·9
31	65·5	52·5	3440	30·5	43	3200	1·0	58	34	1972	93	61·7	57·3
	69	66·5	4580	36·1	54·5	4160	1·0	61	47	2870	91	69	02·6
32	64	81	5174	33	67	4370	·96	52	59·5	3090	85	70·7	59·7

§ 4. To illustrate the difference between theoretical and actual losses Table VIII. was prepared. The heating was calculated by the formula $Pu = q\,r\,i^2$, q having the following values, and r being the resistance per radian of armature circumference :—

Table VII.
Values of q.

—	First Converter.		Second Converter.	
	Single-phase.	Three-phase.	Single-phase.	Three-phase.
$k =$	1·285	1·74	1·375	1·75
$\cos\phi = 1$	14·11	3·85	13·99	3·85
$= ·9$	19·82	4·37	18·55	4·62
$= ·8$	25·27	5·61	22	5·61
$= ·7$	33·52	—	30	—

Table VIII.
Watts Lost in Armature.

Single-phase			
First Converter.		Second Converter.	
Cal.	Obs.	Cal.	Obs.
915	860	225	690
955	914	435	796
1,121	1,510	650	760
1,585	1,450	876	998
2,120	1,910	1,150	1,294
745	904	348	649
2,720	2,296	1,440	1,344
531	790	205	565
995	1,000	475	695
1,520	1,536	725	914
4,100	2,902	1,260	1,468
655	820	200	725
982	1,044	387	816
2,175	1,760	800	1,290
2,715	1,992	890	1,508
1,160	740	255	615
891	700	304	635
805	780	250	605
1,000	1,060	432	725
1,350	1,220	850	850
2,120	1,660	1,440	1,130

Three-phase.			
First Converter.		Second Converter.	
Cal.	Obs.	Cal.	Obs.
318	906	107	294
475	996	202	374
727	1,278	333	432
1,165	1,498	625	462
1,685	1,700	952	490
190	343	69	992
297	740	140	632
272	1,100	226	565
620	1,515	432	261
1,015	2,100	696	180
212	50	78	1,250
380	240	200	1,228
614	420	378	1,290
913	840	607	1,280

Values of r, ohms per radian.
First Converter, ·036 (S. and M.).
Second Converter, ·0446 (Holmes).

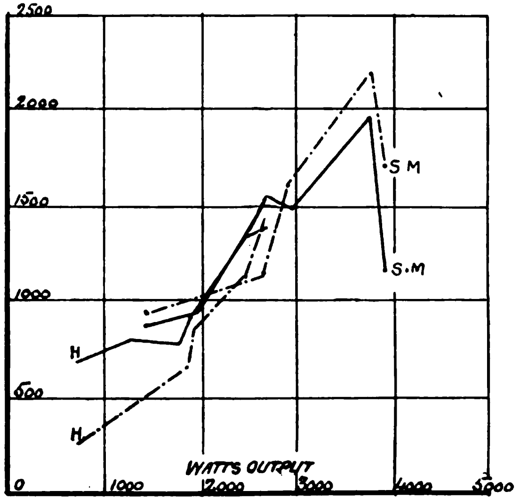


FIG. 11.—Second Under-excited.

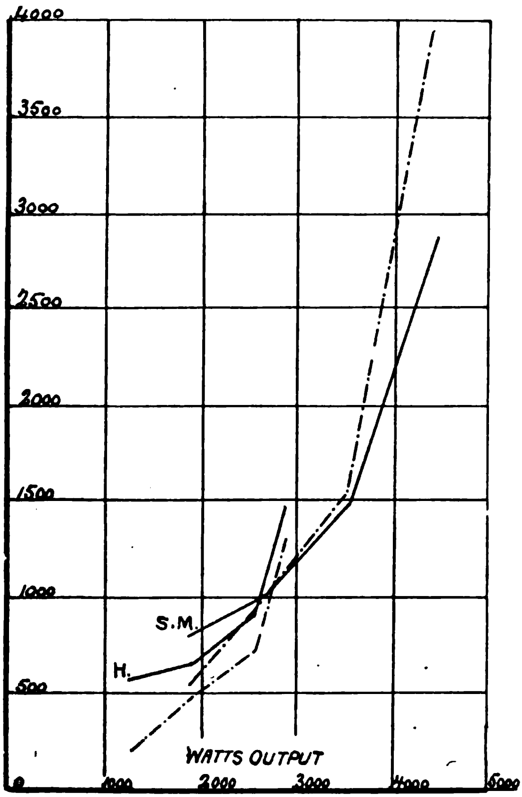


FIG. 12.—Second with Normal Excitation.

The general differences between observed and calculated losses may be better seen from Figs. 11 to 17, drawn Table VIII., the former being shown by full lines, the latter by dotted. In all the curves the ordinates are armature loss in watts, the abscissæ output of each machine. In the single-phase tests the first converter losses were in most cases in excess of those in the second, but the difference between observed and calculated loss was greater in the second than in the first. The three-phase curves are more remarkable. In Fig. 15, which refers to over-excitation of the second machine, the differences are much less in this than in the first. Fig. 16 at nearly normal excitation shows a reversal, which is more strongly marked in Fig. 17, where the second converter field is very weak. The inevitable conclusion from this last set is that the armature reaction harmonic is of sufficient strength to

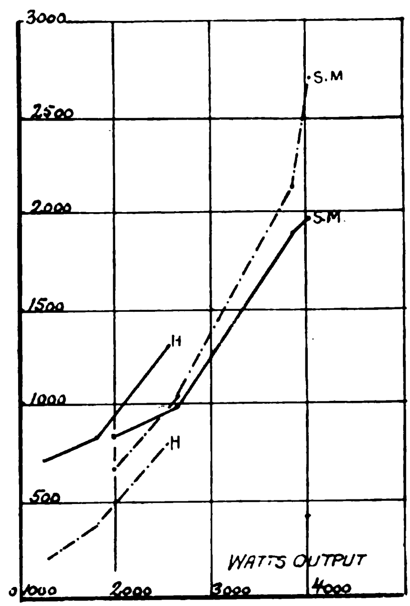


FIG. 13.—Second Over-excited.

disturb the whole circuit, so that the magnetism is rapidly weakened and strengthened in the solid magnet frame sufficiently to cause considerable loss of energy, and that a *change of excitation in the one machine can cause a disproportionate change in the losses of the other,* unless by skilful design and the use of damping coils these fluctuations in the magnetic circuit are minimised. In comparing these machines with motor-generators, it should be remembered that there are similar disturbances in synchronous motors. Beats can always be heard, and each of these means a loss of energy by eddy currents in the iron of the magnetic circuit. In Fig. 18, I have drawn from Tables V. and VI.

* *Vide* Kapp. *loc. cit.* p. 475.

the separate efficiencies of the machines for three-phase working, in which again there is a remarkable effect. The efficiency of the first converter when the second is under-excited *falls* instead of rising with the load, as much as 18 per cent. in one case, *its own field being maintained constant.* This again points to an abnormal increase in the

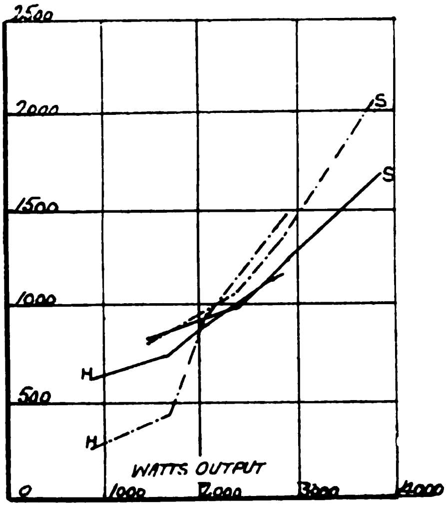


FIG 14.—First Over-excited.

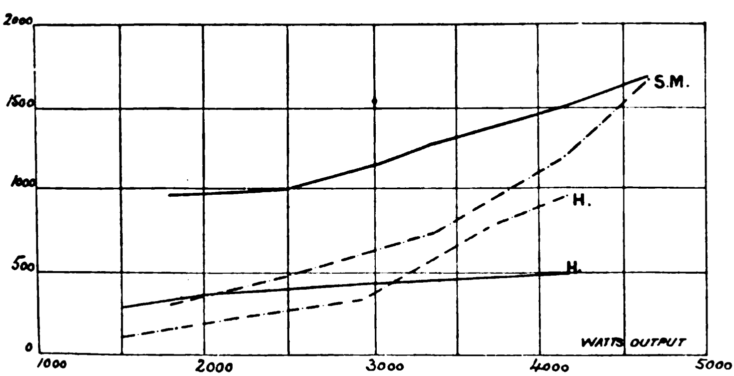


FIG. 15.—Over-excited.

eddy-current losses. There is also a curious drop in curve I_3, which indicates that the sudden loss of total efficiency shown in Fig. 10 for under excitation takes place in the first converter. It remains, then, to prove experimentally that these losses are caused by armature reaction, and to estimate their magnitude.

§ 5. I have worked out in a former paper* a numerical example of the losses due to eddy currents in magnet cores. These can be calculated when the dimensions and conductivity of the core and the ampere-turns producing the change are known. Thus if c be the radius of the core, l its length, μ the permeability, ρ the specific resistance, f the frequency of alternation of magnetism, and (I T) the

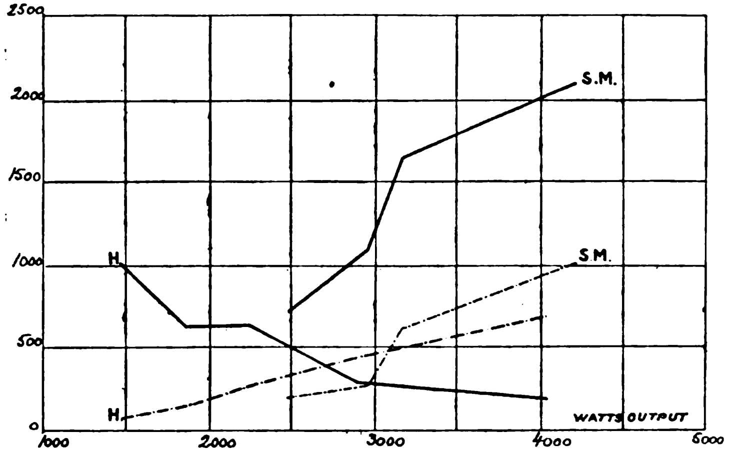


FIG. 16.—Slightly Under-excited.

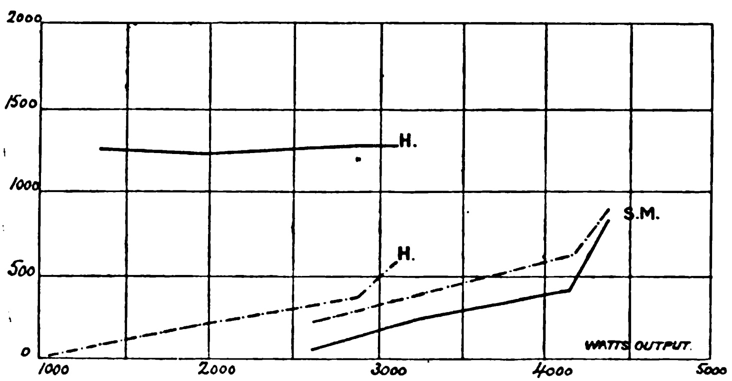


FIG. 17.—Under-excited.

maximum value of the ampere-turns causing the change—this being sinusoidal—then to a first approximation, the watts lost †

$$w = \frac{4\pi l}{\rho}(\pi^2 c^2 \mu f)(\mathrm{I\,T})^2\, 10^{-7}.$$

* "Rotary Converters and Phase Swinging." *The Electrician*, Sept. 27 and Oct. 4, 1901.

† Heaviside, *Electrical Papers*, vol. i. p. 353.

To apply this to explain the difference between the observed and calculated losses it is first necessary to know the ampere-turns of armature reaction for any given condition of working. This was first done in these experiments by placing a hot-wire galvanometer across the otherwise unused series windings of the Holmes machine, these forming an exploring coil of 58 turns. About one volt was observed when running light, and photographs were taken showing the influence of phase swinging on the magnetic circuit when unprovided with damping coils. It occurred to me later that this voltage is sufficient

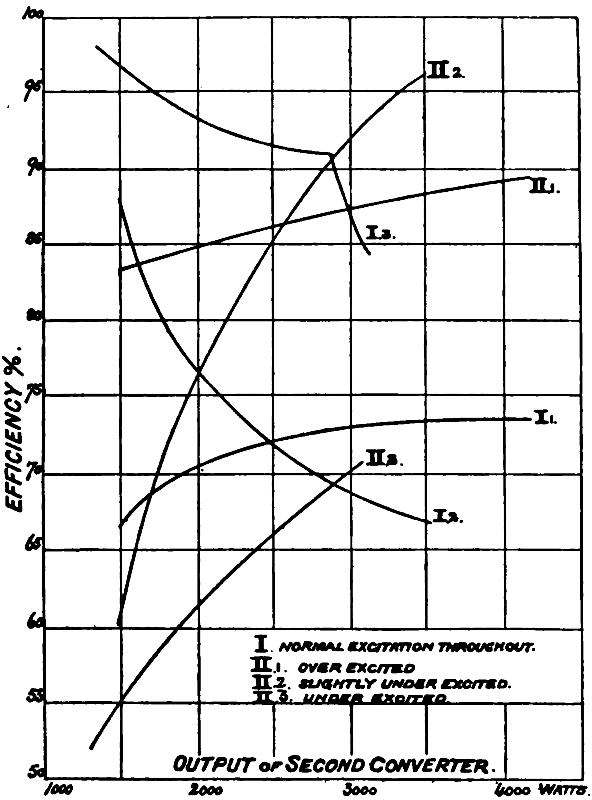


FIG. 18.—Variation of Efficiencies—Three-Phase.

to give good readings using the oscillograph as a dead-beat galvanometer, and I ran the oscillograph motor at the same time to see whether the harmonics of armature reaction could be directly observed. The results are shown in Plate I., the corresponding conditions being given in Table IX.* These curves are records of the

* The letters N, E ; U, E, etc., in the top row of numerals indicate the excitations of first and second converter respectively for each vertical column of curves.

rapid magnetic changes occurring within the core when this is worked at various saturations and with different values of armature reaction. They are, in effect, the voltage in the secondary coil of a transformer of which the magnetic frame is the core and the armature the primary. They are interesting, as showing, for the first time, I believe, what kind of action really goes on within the magnetic circuits of these machines, and, I have reason to think, of all kinds of dynamo-electric machinery, for I have obtained similar curves (Fig. 19) from continuous-current motors separately excited, driven from cells, and running light. The most curious point, I think, about the curves is the absolute constancy of form observed, except when a phase swing starts. All the ripples remain steady, and the curves can always be repeated. The same applies to the records of Plate I. This method of examination seems to me to afford a most delicate test of whether the armature is perfectly symmetrical in the gap, and should be

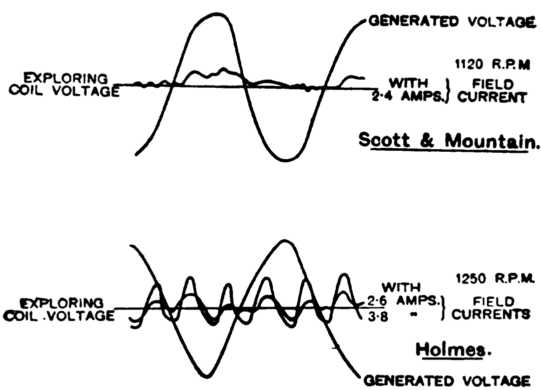


FIG. 19.—Oscillations of Magnetic Fluids, in Separately Excited Continuous-Current Motors Running Light.

useful in the study of flicker, or to indicate the magnitude of the disturbances, mechanical or magnetic, caused by the armature running out of truth. The records of Plate I. are no doubt complicated by the presence of these oscillations, especially the more rapid movements in the three-phase curves.

A detailed analysis of the curves in Plate I. would be very laborious, but some general conclusions may be drawn. Taking the first converter single-phase set first (curves 16 to 20 in Plate II.), it is seen that the light load losses are practically the same for all excitations, and that over-excitation more than doubles them for the same load, for the amplitudes of the curves are much the same, and the strip resistance was 16·1 ohms in 16, but only 6·1 in 20. The first three and 20 show a change of phase of the harmonic of about 45 deg., backward in 16, 18, and 20, forward in 17. Under-exciting the first machine causes the harmonic to lag with respect to the voltage more than in the other cases. This double frequency harmonic alternately weakens and

strengthens the flux in the gap, and this can be seen by 19, where it is in the first half opposite to and in the second in phase with the voltage. The motor reaction, curves 1 to 5, shows a remarkably constant type; there is a quadruple harmonic present, and the phase of this is moved 180 deg. of its own between 3 and 5. The reason for the existence of these still higher waves and the meaning of this shift of phase I have not had the time to examine more fully,* but it is of interest to see that the same changes occur in the three-phase curves, and that, as before, the losses are greatest with an over-excited first converter.

TABLE IX.

—	Curve.	1st conv. Field Current.	2nd conv. Field Current.	2nd conv. Con. cur. output.	Total ohms in strip circuit. Light.	Total ohms in strip circuit. Loaded.	Revs.
Single-phase (Holmes)	1	2	1·93	28	21·1	21·1	1,150
	2	2	2·72	32	21·1	21·1	1,000
	3	2	3·29	34·5	6·1	23·1	1,075
	4	1·6	2·7	22	13·1	23·1	1,000
	5	3·1	2·7	31·5	29·1	33·1	1,020
Three-phase (Holmes)	6	1·9	3·62	34	3·1	4·1	1,000
	7	1·9	2·4	41·7	4·1	4·1	1,020
	8	1·9	1·95	30	4·1	6·1	1,000
	9	1·6	2·7	20	2·1	2·1	1,000
	10	3·1	2·7	29	11·1	11·1	1,000
Three-phase (Scott and Mountain)	11	1·9	3·62	33	2·1	2·1	900
	12	1·9	2·4	39·5	2·1	8·1	1,030
	13	1·9	1·95	30	2·1	4·1	1,000
	14	1·6	2·7	20	2·1	2·1	1,050
	15	3·1	2·7	20	2·1	2·1	1,000
Single-phase (Scott and Mountain)	16	2	1·9	24	4·1	16·1	1,060
	17	2	2·7	20	4·1	14·1	1,080
	18	2	3·2	30	4·1	9·1	1,060
	19	1·6	2·7	non-p.	6·1	6·1	1,060
	20	3	2·7	15/25	6·1	6·1	840

To return to the determination of the ampere-turns of reaction. Let e be the voltage generated in the exploring coil, as found by a hot-wire galvanometer or from the curves, and let there be s turns on the coil. Then, when f is the frequency of oscillation (which will not be simply that of the machines if there are harmonics),

$$e = 4\,N\,f\,s/10^8,$$

* It varies with both excitation and load.

where N is the mean flux through the coil. Here e is root mean square, and N an ordinary average, hence the true value of

$$N = \frac{e}{4fs} \cdot \frac{\cdot 637}{\cdot 707} \cdot 10^8.$$

but s is 58 on the Holmes machine, 55 on the Scott and Mountain, and f and e are observed; thus N is known. Now, N = Magnetomotive force/reluctance. Thus writing

$$N = \frac{4\pi}{10}\frac{it}{R}, \text{ the ampere-turns } it = \frac{NR}{1 \cdot 257}.$$

The maximum value for sine waves is 1·57 times this. Therefore

$$(I\,T) = 1 \cdot 25\ N\,R.$$

For the Holmes machine, R = ·005, as found from the magnetisation curve for 2·7 amperes, so that

$$(I\,T) = 2{,}420\ e/f;$$

and when the speed is 1,000 revolutions per minute,

$$(I\,T) = 146 \text{ per volt in the exploring coil.}$$

For this machine the mean length of solid iron core is 100cm., the radius 7·8cm. Taking the specific resistance as 10,000, and the permeability as 100, the watts lost at 1,000 revolutions per minute are *125* per *100* maximum ampere-turns.* Thus we have finally, since the loss depends on the square of the reaction ampere-turns, *266 watts per volt.* Considering the double frequency harmonic, this loss is reduced from 266 to 65 watts. When there is little or no phase swinging, the voltage is from two to three at medium loads. The oscillograph calibration was 2·1 cm. deflection per volt with 10·1 ohms in circuit, from which the amplitudes of Plate I. may be worked out in volts.† Taking an equivalent sine maximum of 2·5 volts, with the double frequency harmonic of Curve 2, there are *102 watts* lost by eddy currents in the magnet core. It will be seen from Fig. 12 that this accounts for a good deal of the discrepancy between the observed and calculated loss in the Holmes machine, and I think that all the wide differences are due to the same cause.

§ 6. *Effect of Armature Reaction on Wave-Form.*—The relation between excitation and phase displacement has been shown in Figs. 4, 5, and 6. These were verified by direct observation in the oscillograph and the waves sketched. The voltage curve remains singularly constant in shape under all conditions, but the current wave, depending as it does on the phase relations of the two machines, is very sensitive to changes in the magnetic circuits. The chief cause of the variation of form is the harmonic of armature reaction, and the phase of this changes considerably with regard to the main wave.

* Magnetic leakage reduces the intensity of the eddy currents towards the yoke, thus diminishing the loss, but the working permeability is about 400, and the eddy current loss is directly proportional to this.

† The curves as printed are about quarter full size.

Plate II. contains a selection from the wave-forms sketched. The current curves of Plate II. are not all to the same scale. Tables V., VI., and IX. give the true values. Curves 1 to 22A are for a single-phase working, the rest for three-phase. On all the curves but 22 and 22A the conditions of excitation are indicated by the letters O E, U E, or N E, signifying over, under, or normal excitation. In 14A the phase displacement from lag to lead as the excitation is increased in the second converter is shown; 22 gives the magnitude and nature of the wave changes during moderate phase swinging, and 22A is the single curve in which the brushes have been moved from mid-position, A_1, corresponding to a slight backward shift, and A_2 to the extreme backward shift when the sparking was too heavy to be long continued. The first set, from 1 to 6, were taken after the readings of Table IV. These were approximately repeated, as in Table X., to which the curves correspond. In these the full effect of change of excitation can be seen both on form and phase. The strong harmonic of Curve 1 always appears when the second machine is fully excited and the field of the first gradually reduced, the speed being maintained constant by varying the armature current. The lateral shift of the harmonic is most marked from 1 to 2, the other curves showing chiefly a variation in its amplitude.

Table X.

Field Current of First Converter, 2 Amperes; Second, 3·7 Amperes.

No. of Curve.	First Converter input.		Second Converter input.				Second Converter output.	
	V.	A.	V.	A.	W.	Cos ϕ.	V.	A.
1	92	13·5	62	13·6	532	·65	0	0
2	82	37	54·5	40	2,190	1·0	79	19·5
Field Current of First Converter, 2 Amperes; Second, ·7 Amperes.								
3	80	35·7	48	39·5	1,910	1	68	19·4
4	82	13·5	52·4	20·5	472	·44	0	0
Field Current of First Converter, 2 Amperes; Second, 2 Amperes.								
5	79	16	48	30	504	·35	0	0
6	78	30	45·6	37·5	1,484	·87	61	15

Curves 7 to 21 were taken simultaneously with the readings of Table V., as indicated, and it is of interest to trace the nature of the change with load in each case of excitation. In 11, for example, the current being more than double that of 7, the harmonic has moved over 60° and its amplitude increased.

The curves from 23 to 40 are for three-phase working, and partly correspond to Table VI. In the last eight the first machine was driven mechanically by belting, but the differences between these and the previous nine are not important. It is evident that the field distortion is extremely small when working three-phase compared with single-phase. With the exception of a weak third, harmonics are almost absent. There is a slight distortion of the field as in a continuous-current motor, which is met in practice by suitable brush displacement, but phase-swing is difficult to start, and is not maintained to the same extent as in single-phase running.

It may be concluded from these experiments that over-excitation of the second machine or motor improves the stability of the system, but that if the generator or first machine is under-excited, although the ratio of the flux densities in the gaps may be kept constant, there will be both an increase in the eddy-current losses and in the instability of working by reason of phase swinging. It is more economical then to expend energy in over-excitation than to allow phase swing to start and stop it by damping coils. These are necessary in any case where there is a periodic irregularity in the generator speed, but they depend upon a well-marked change in the magnetic circuit, and when this is saturated the magnitude of the disturbance is less.

Eddy currents in continuous-current machinery have been previously thought of as almost entirely located in the armature and pole-faces. From these tests it is seen that with a periodic oscillation through the whole magnetic circuit the losses in the solid cores are considerable, and I believe that the greater part of the eddy-current loss found by any of the usual tests takes place in the solid frame. If this is to be prevented, the mechanical construction must be as accurate as in engine fitting. The pole-faces must be bored smooth and set to gauge. The armature must be as true as a gun barrel and perfectly centred. Its shaft must be stiff enough to prevent the least bending and must not whirl at any speed, for the most violent magnetic changes will be set up if this occurs. If it is attached to overhung pulleys or flywheels, which cause bending, these must be compensated as in a balanced engine. Of course, all this is if it is worth doing. It is merely a question of first cost—the user pays for the energy lost in the damping system.

I hope that these experiments will be preliminary to others on substation machines under working conditions, and a rather lengthy series of tests on the effect of brush position on efficiency and wave-form has already been made. I think it will be admitted that our experimental knowledge of the reactions in alternators and converters, and in continuous-current machinery also when subject to changes in the mechanical torque, is at present imperfect. I venture to hope that the experimental methods of studying the changes in the magnetic circuits given in this and last session's paper* will contribute a little to a more thorough knowledge of what really goes on within both fields and armatures of dynamo-electric machines in general, and lead to an improvement in their efficiency and stability of working.

* The *Electrician*, May 30 and June 13, 1902; the *Electrical Engineer*, April and May, 1902.

Mr. JOHN H. HOLMES (*Chairman*) said that the Institution was highly favoured to have had such an important paper read before it. Dr. Thornton's previous paper had been of very great interest and this was a continuation of it, while the points he had now brought out were very interesting. It had probably been recognised, to some extent, that changes took place in the field magnets of continuous-current dynamos when there was something wrong with the armature, if it was very much out of balance, or if there was a short circuit, but we had no idea as to what those changes actually were. The methods introduced for detecting changes in these magnets were very ingenious, and seemed to make the thing much clearer. The question of rise in voltage on field coils of dynamos had certainly been observed and had led to inquiry. It was quite possible that the extraordinary rise in voltage noticed on shunt windings when the armature was very much out of balance, or what the Americans call the "bucking" of dynamos, might find some explanation in this paper. Mr. Holmes.

Mr. G. RALPH, after congratulating Dr. Thornton on his excellent paper, said that, unfortunately, his knowledge of the subject was so slight that he could not criticise any portion of the paper, but he had no doubt that many others, like himself, had occasionally in the course of their work, met with some phenomenon which was puzzling at the time, and for which they could not find any explanation. Cases like these should be taken to friends like Dr. Thornton to be solved. Mr. Ralph.

It might be interesting to them to describe a curious effect which came under his notice a few years ago. He was engaged in carrying out some efficiency trials of direct-coupled engines and single-phase alternators at a Corporation Supply Station in the South of England. The conditions were as follows :—The engine was a double-cylinder single-acting engine. The revolving armature was of the disc type, with no iron in it, of the well-known type made by Siemens, Ferranti, and others. The alternator field was separately excited. When the machine was running with *no* current in the armature, the potential across the exciting terminals of the field was 80 volts, and the exciting current agreed with this potential difference and the resistance of the field. When, however, load was put on and full current was flowing through the alternator armature, the potential across the exciting terminals rose 50 per cent. or more, although everything remained exactly the same as before, that is, the speed of the alternator and exciter was unchanged, the exciting current and resistance in the circuit remained unchanged and yet the mere fact of putting load on the alternator caused the exciting voltage apparently to increase to this degree. When this was first noticed it was concluded that the voltmeter had gone wrong. It was an electro-magnetic type of instrument. This was taken off, and a Cardew hot-wire voltmeter and also a Kelvin multicellular electrostatic voltmeter substituted with exactly the same result. A similar effect was noticed the following day on the trial of a smaller alternator. When he returned to the works after these trials were over he tried to get the same effect on other alternators in the place—at the time in the course of construction—and failed utterly. Some doubt was then cast on his figures, and the engineer in charge of the station

Mr. Ralph. where the effect had been noticed was written to and asked to try again and his (Mr. Ralph's) figures were repeated every time. He would like to ask Dr. Thornton if he thought an effect like this would be produced by armature reaction causing a very strong fluctuation in the field magnet cores. He believed that in these particular alternators the field was fairly weak, which, as pointed out in the paper just read, would magnify any evil of this sort. He had never heard a satisfactory explanation, and thought it might be interesting to mention the case.

Mr. Heaviside. Mr. A. W. HEAVISIDE then proposed a vote of thanks to Dr. Thornton, and in suggesting a visit to the dynamo room of the college, said it would be very profitable to see the actual experiments.

Mr. Eugene-Brown. Mr. E. EUGENE-BROWN seconded, adding that he was well acquainted with the subject itself, and was sure the experiments with the oscillograph would be full of interest.

[The members then proceeded to the dynamo room, where Dr. Thornton went through and explained the experiments, and also answered the questions which were put to him.

The discussion was continued informally in the engine room while the experiments were being shown. The curves of Plate I. were projected from the oscillograph on to a screen, and the change from one to the other condition made gradually by the field rheostats. Periodic movements in the curves, due to phase swinging, were started by throwing load on and off the second converter. Messrs. Holmes, Heaviside, Snell, and Ralph took part in the discussion, and in reply to them the following points were brought out by Dr. Thornton :—]

Dr. Thornton. Dr. W. M. THORNTON : It is not possible to prevent armature reaction itself, and it is therefore necessary to check, in every possible way, the communication of disturbance to the magnetism. This may be done in any machine by damping coils surrounding the poles, by preference, close to the armature. These act most efficiently when the iron frame is solid, and depend chiefly on the eddy currents started by magnetic waves sent radially into the core by the strong currents induced in them by slight changes of magnetism. Since they are useful even when the iron is laminated in making any oscillation more dead beat by opposing the initial change I would advocate laminating the magnet frame of continuous current machines; for, in the first place, it would diminish eddy current loss. It is generally taken that the no-load eddy current loss, which can be found, remains substantially the same at all loads, but according to these curves this loss is about twice as great at full load in the second converter. In cases of parallel running, with compound traction machines for example, the currents in the equaliser circuits, and therefore the voltages would more quickly adjust themselves. Design in general is simplified by the accuracy with which the permeability of these plates can be found.

The value of amortisseurs in preventing fluctuations is such that one may reasonably forecast the time when every large machine, either continuous or alternating, will be fitted with them, for though by the use of high-speed engines and turbo-generators, irregular turning movement is less, yet the governing of both is far from perfect, and with the small moment of inertia of the latter, sudden or periodic load

Dr. Thornton.

may be very disturbing to the magnetic circuit unless protected in this way.

These fluctuations do not entirely depend on armature reaction, for as shown by Fig. 20 they are obtained in the exploring coils when *no current is passing in the armature.* That is to say, they exist by reason of the variation of the reluctance of the air-gaps due to the armatures running slightly out of truth. It is not possible in either case to observe any side movement, nevertheless, both armatures must be slightly eccentric in the gap or the shafts bent. A quadruple harmonic would be caused by a bent shaft or by the armature "whirling." The fact that the effect is greatest when the field is strongest confirms this view.

In Fig. 20 the current required to drive the oscillograph (about ¼ ampere) was being taken from the slip-rings. To eliminate the effect of this the first machine was used to give current for the oscillograph motor only, at the same time connecting one strip to the exploring coil on the second machine, which was belt driven, and entirely disconnected from the first. The curves remained the same shape but were slightly smaller. It was not possible to draw or photograph them by reason of their slow procession across the screen.

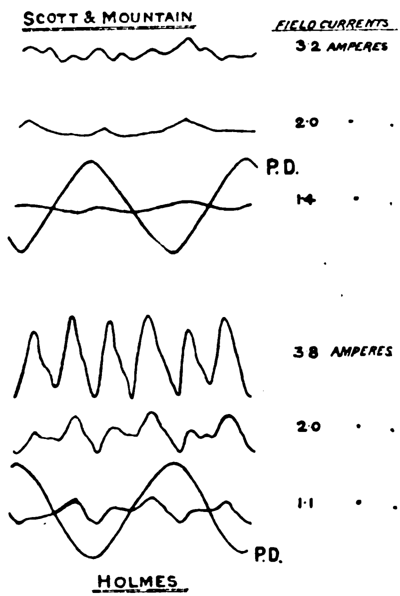


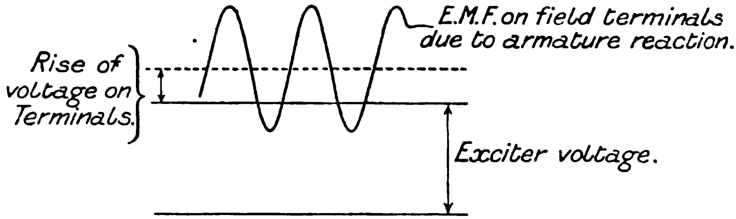
FIG. 20.

With regard to Table VIII. the armature losses are calculated from the continuous current having regard to the irregular distribution of current in the conductors. The energy taken into or supplied by the armature is a function of both voltage and current, the energy flux entering the conductors from the surrounding medium at right angles. One may thus follow the transfer of energy from the source of supply to the eddies in the iron through the magnetic flux acting as an elastic intermediary, and see it dissipated there without the armature current showing all that is going on, though there will be inevitably either a rise in current or drop in voltage whenever the effect is taking place. To obtain a general expression for the losses covering both voltage and current changes, is, I think, impracticable, but by reference to Table VI., curves 30 to 32, it will be seen that whenever there is a great difference between the observed and calculated losses it is accompanied by a large drop in voltage.

In reply to Mr. Ralph's question the effect is, I think, as follows :—

Dr. Thornton.

There was first an alternating armature reaction superposed on the constant excitation. This field was weak, and when the armature was strengthening the field the permeability of the core would certainly be less than when acting against the field magnets. The alternating voltage induced in the field windings depends on how this permeability varies. If it is simply harmonic no rise in voltage can, I think, occur across the exciter terminals, but if it varies (as, for example, in the large wave of



curve 1 Plate I. in the paper) with a pointed top to the wave, that is the point where the voltage will be greatest, for there the permeability is changing most rapidly. In this case the induced voltage in the field windings will be greater above the line of exciter voltage than below and there will be a rise of voltage at the terminals, though the exciter voltage remains constant. The instrument must have been capable of reading both alternating and continuous voltage.

I wish to thank several senior students who have helped me in this work.

NEWCASTLE LOCAL SECTION.

RAILWAY BLOCK SIGNALLING.

By J. Pigg, Associate Member.

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The subject of signalling generally is of the most interesting character possible, and code signalling of some form or other seems to have been in use for the conveyance of intelligence to points beyond the scope of man's vocal organs during all periods covered by history. If time permitted we might commence with a quotation from Exodus, and pass on by easy stages to the methods of signalling of ancient Egypt, the heliograph of Alexander the Great,* the torchlight signalling of the Romans, the adaptation of the Greek clepsydra to alphabetical signalling, the drum, smoke, and fire signals of savage peoples, the later beacons and watch-towers of our own and other countries, the revival of torchlight signalling between the Scottish mainland and the Shetland Isles by the Rev. James Bremner early in the eighteenth century, and so to the achievements of the brothers Chappé on the Continent with semaphore signalling, and Lord Murray's shutter form of telegraph in this country in the period immediately preceding the introduction of the electric telegraph. It is interesting to remember that although accounts of the introduction of the electric telegraph now read like ancient history, yet we are still comparatively near to the era of the semaphore telegraph. Although formally adopted by the French Directory in 1793, Chappé's system was not fully completed in Russia until 1858, so that there may be some here who, without being of a patriarchal age, and probably taking but little interest in the subject at the time, may still be said to be contemporaries of the semaphore telelegraph.†

The more particular form of signalling to which this paper refers has also an historical side, which is of considerable interest to the student of the evolution of railway signalling. There are, moreover, other aspects of the subject which are of great importance. These are the statistical, involving consideration of reams of figures relating to the development of the system and its effects; the constructional, with its sight-destroying and brain-puzzling diagrams, illustrating the principles of design and the circumstances to be met; and the operative, with its enormous mass of detail for working purposes. All these points of view, including the historical, are of the greatest importance

* See Presidential Address of Sir Henry Mance to Institution of Electrical Engineers, January 14, 1897.

† For further information on pre-electric telegraphs see a most interesting lecture by Mr. Alderman W. H. Bailey (now Sir W. H. Bailey) at Salford in 1883, "Telegraphs of the Ancients."

in their several ways, but they require more time to even skim them lightly than is available here.

There is, however, still another aspect of the subject which, to the writer, seems to be of supreme importance—the effectiveness of the system—or, in other words, its adequacy for the purpose for which it has been designed. However interesting other aspects may be, there are none of such importance as this. Freedom from failure—and the consequences—is the touchstone of any system. When, as in railway signalling, the consequences may be serious, the necessity for reliability is greatly increased. We might illustrate this aspect of the subject by quoting figures to show that travelling by railway is vastly safer than by the old stage coach, the newer motor-car, or even, in view of recent lamentable occurrences, the electric tram,. inasmuch that a smaller proportion of travellers are killed or injured by the former than by any of the latter methods. It is the present proud boast of English railways that they have not killed a single passenger through an accident to the train in twelve months, and such a record, considering the millions carried, is a magnificent testimony to the care and attention devoted by those responsible for the organisation, direction, and operation of the enormous traffic carried on our railways. Yet accidents do unfortunately occur, and, if I may so put it, it is small comfort to the sufferer to know that he is only a unit in a small percentage of fatalities, and should be glad that the percentage is not larger.

Objects of Block System.

There is no need on this occasion to labour the point of what is meant by the term "block." Quoting from the explanation given with the standard rules, we find that "the object of the system of block telegraph signalling is to prevent more than one train being in the section between two block signal-cabins on the same line at the same time," or from the Board of Trade "Requirements in regard to the Opening of Railways": "The requisite apparatus for providing by means of a block telegraph system an adequate interval of space between following trains, and, in the case of junctions, between converging or crossing trains." These extracts, by the use of the word "telegraph," seem to limit the term "block" to the electrical signalling apparatus, and ignore the outdoor mechanical signals as part of the "block system." Definitions of the system which may be deduced from these quotations seem to the writer to be narrow, and inadequately indicate the functions of the two main classes of apparatus used for the regulation and control of traffic. Certainly it is impossible to consider either class alone in connection with the results to be obtained. However, one oftens obtains a more vivid idea of a comparatively unfamiliar subject by the use of a simile, and the following quotation from a popularly-written article in the *Pall Mall Gazette* has at least the merit of being graphic, if incorrect: "The world-famous block system, which, to furnish a simple parallel, decrees that no train may leave the bottom of a flight of stairs until both the latter and the landing beyond have been guaranteed clear."

The fundamental basis of block signalling is, therefore, the preservation of "an adequate interval of space" between trains, whether "following," "converging," or "crossing"; the object is safety; and by convention or rule or regulation it is provided that not more than one train shall occupy one pair of rails of a certain portion of the line at one and the same time. For signalling purposes the line is divided into discontinuous sections, or blocks, and cabins are erected at suitable points in which, as required by the Board of Trade, the means of actuation of all points and signals connected with the running lines are assembled, and in which is also placed the electrical signalling apparatus. The *block section* for the time being is the distance between the two cabins in electrical communication with each other at the time. These two cabins may not be the two nearest to each other; under certain circumstances intermediate cabins may be switched out and become inoperative for a time. Ordinarily the space limit between trains is the length of the *block section*, and it is never less than this; but where the distance is 400 yards or less the *space limit* may be two or three such sections. It is not necessary that the space limit be the same at all parts of the line, and, as a matter of fact, no attempt is made to obtain uniform distance between trains. At some places it may be only a few hundred yards, and at others, again, it may be several miles. Nor is it necessary that the space limits within any given portion of line should be constant. In many cases, as already alluded to, means are provided by which, for economical reasons, the sections and space limits may be purposely varied. In every case, however, the minimum distance to be observed depends upon traffic considerations, with which we are not concerned here, and upon the distance in which the heaviest and fastest trains can be brought to a stand on the gradients obtaining. In some cases where there are heavy gradients we may find that whilst the *block sections* are the same for the up and down lines, the *space interval* is greater for the line with the falling than for that with the rising gradient.

Main Divisions of Apparatus.

A cursory examination of the subject shows that the apparatus employed in railway signalling may conveniently be divided into two great classes—the outdoor mechanical signals, and the electrical signalling apparatus. The former are used for the actual control and regulation of the movement of traffic; the latter is provided for perfecting the arrangements for the exhibition of the proper signals for the time being, and is, therefore, an auxiliary. The whole art of railway signalling, therefore, consists in the exhibition of suitable signals to the controllers of trains as they approach the sections or blocks.

The forms of the mechanical signals in use in this country are well known, but there are one or two details respecting them which may be touched upon here. A certain class of signal, the "distant," may be passed when in the "on" position. Its indication is of a cautionary character only when in the position named, and shows that the section ahead has not been prepared for the free passage of the train, and that

the driver must be prepared to stop at the next signal in order, the "home." Drivers, however, are by rule required to be prepared to stop at any obstruction that may be found to exist between the "distant" and the "home." Naturally, the positions of "distant" signals must be at such distances from the "home" signals as to allow any train to be brought to a stand at the latter if necessary, and the location of the "distant" is also always made with a view to a clear sight of it being obtained as early as possible before it is actually reached. Other signals than the "distant" are "stop" signals, which must not be passed by trains when in the "on" position, unless special permission is given. Such permission may be given by "calling-on" signals which have a cautionary character when in the "off" position; or by lamp, flag, or hand signals, supplemented in some cases by verbal and in other cases by written instructions. 'Home," "starting," and "advance" signals are all "stop" signals, as are also siding and cross-over road signals.

"Stop" signals have other characteristics than those already referred to. Thus besides being indicators of the conditions existing with reference to the continuance of the journey, they are also position signals in that they mark the points which must not be passed by any portion of a train when the signals are in the "on" position without special permission. They, therefore, are used to protect the fouling points. At junctions the "home" signals—and the "distants" where more than one are provided—are also route indicators for the divergent lines, since each such line is provided with a separate "home" signal. These signals are erected under the same rule for all places, and the recognition of the road prepared, by drivers, is thereby facilitated.

Interlocking of Points and Signals.

The means of actuation of all signals have to be interlocked with each other, and with the means of actuation of the points, so that the latter must be set before the signals for them are lowered; so that conflicting signals cannot be lowered at the same time; so that points cannot be moved when the signals are in the "off" position; and the points must, as far as possible, be interlocked amongst themselves so that risk of collision is avoided. Cabins must be so situated as to provide the best possible view of the line, and to enable the signalman to see the arms and lights of the signals and the working of the points. Where signal arms and lights cannot be seen they are to be repeated in the cabin. Facing points must be avoided as far as possible, and must not be more than 200 yards from the cabin, and trailing points not more than 300 yards. All facing points are to be fitted with facing-point locks and locking bars, and with means for detecting failure in the connection between the signal cabin and the points. The length of the locking bars must exceed the greatest wheel base between any two pairs of wheels of vehicles in use on the line, and stock rails are to be tied to gauge by iron or steel ties. All points, whether facing or trailing, are to be fitted with double connecting rods, and must be worked or bolted by rods and not by wires.

These conditions all make for safety, and on their stringency it is unnecessary to comment here. It is impossible to over-estimate the importance of the interlocking of points and signals at important junctions or busy centres of distribution. Such places as busy passenger station yards, whilst they can be, and are, worked without the ordinary electrical portion of the block system, could not possibly be worked without interlocking at anything like their present efficiency, or with the freedom from accident that obtains at present. The interlocking in busy yards not only exists between the different levers in any one cabin, but there is, necessarily, also a large amount of inter-cabin control where a yard is worked by a number of cabins. How intricate is the control which must be established will be readily seen from an inspection of the signalling plan of any large station yard.

Power Signalling.

We have, hitherto, considered the working of points and signals exclusively from the point of view of manual operation. The tendency to the use of power, under manual control, for this purpose is at the present moment becoming very marked. The working of points and signals by electrical power has, of course, been in operation at Earl's Court Station on the Timmis system for some time. The Great Eastern Railway Company has put down an installation of the Westinghouse electro-pneumatic signalling system at Bishopsgate, and the North-Eastern Railway has recently fitted up two cabins at Tyne Dock with the same system. The London and North-Western Railway Company has put down a large installation at Crewe, where all the necessary operations are carried out by electrical power. This system, commonly known as the "Crewe" system, is to be put down at an important junction on the North-Eastern Railway at York. Messrs. Siemens and Halske also have a very complete system of electrical power signalling, installations of which have been put down at various places on the Continent. It is impossible within the limits of a paper like this to enter into details of any system, or even to consider their advantages. The tendency to the use of power for the purposes alluded to, in preference to hand labour, is merely noted as a development which is just in its first stage. Nethertheless, it may be considered as certain that the subject has received careful attention from railway engineers, and that such installations would not be put down, even as experiments, unless there was a fair prospect of their being successful in promoting either efficiency or economy.

Electrical Equipment and Operation.

Turning, now, to the electrical equipment for the signalling of a railway, we find a large number of matters of great importance which the time available will not allow of discussing. Such points are the signalling of single lines, and the particular conditions to be complied with; the use of permissive systems of signalling, with recording instruments for certain classes of line; the employment of the telegraph and the telephone as auxiliaries in train signalling; gate-

crossing equipments; the repeating of signals, lights, points, etc.; the apparatus used to indicate when trains or vehicles are standing at a signal which is out of sight of the signalman, or where the line is not clearly visible; rail treadles or insulated rails and their uses, or other special devices which go to make a complete system. We have not even time for an analysis of the codes and regulations under which signalling is carried on; for a discussion of the relative merits of three-wire or one-wire systems; or for the much-debated question of the best form of instrument, from either the electrical point of view or from the operator's standpoint. The latter question is quite as easy of settlement as the question of the best arc lamp or the best motor, municipal *versus* private trading, provision for the depreciation of plant, or any of the numberless matters on which many people agree to differ more or less amicably.

The electrical equipment for a block section is very simple, but the amount of apparatus to be provided at any block station depends upon the character and importance of the place. If we take the simplest example of such a station, say a mere passing place, we shall find that where single-needle apparatus is employed the equipment will consist of two bells and four such instruments. One bell and two instruments will be in electrical communication with the block station on the up side of the cabin considered, and the remainder in connection with the cabin on the down side. The bells are for the purpose of giving and receiving information, or for the making of arrangements in accordance with the voluminous code which provides for all circumstances that may arise in connection with the working of traffic. The instruments are also used to a slight extent in connection with the code, but they have other and more important duties to perform, in that they are intended to indicate continuously the condition of the lines of rail they represent.* There are numerous forms of block instrument in use, each embodying, no doubt, its designer's idea of the best method of performing the desired operations, but with constructional details we are not at present concerned, and so far as their indications are concerned they are all alike in that they represent the condition of the line by convention only.

A study of the code and regulations for the working of traffic shows that there are three conditions of the line which the block instrument should indicate. These are:

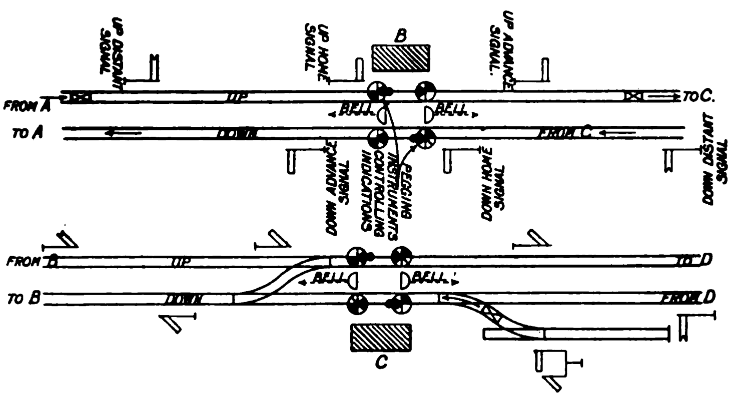
"LINE BLOCKED," "LINE CLEAR," and "TRAIN ON LINE."

The first is the indication to be given when the section is clear of trains altogether; the second is the indication required when the section has been prepared for a train, but which has not yet entered the section; the third is the indication provided to show that a train is actually passing between the two block stations. Each of these indications is "permanent," in the sense that it is required to be exhibited during the whole time the condition it represents continues; the indications on the two instruments representing a line of rails, in the two cabins,

* On the N.E.R. the use of the indicators in connection with the code has been discontinued since the paper was read.

are the same, and the indications are under the control of and made by the man towards whom the train signalled is proceeding—*i.e.*, at the exit of the section.

The operations necessary to the passage of a train may be briefly described, it being premised that the character of the train is immaterial for the present purpose. Suppose a train is approaching station "C" on the up line and will pass on to "D." Station "C" askes station "D" by code "Is line clear?" (there are 11 variants of this signal). If the train may proceed, "D" replies by code to that effect, and gives an indication on the block instrument for the up line at his own station and at "C," which reads "Line clear." This indication remains until a further stage of the operations, and serves as a continual reminder to "D" that he has given permission for a train to leave "C," and to the signalman at the latter station it serves as a continuous reminder that he has obtained permission to forward a train. Under the conditions now obtaining the signalman at "C" may place his mechanical signals in the "off" positions to allow the train to proceed to "D."



When the train is leaving "C" the signalman there sends the "Train entering section" bell signal to "D," who must acknowledge it and change the position of the block indicators in his own and "C's" cabin for that line to "Train on line," and this indication serves as a continuous reminder to both signalmen that there is a train *in the section.* When the train has passed "D" and gone forward under precisely similar conditions, the signalman there advises "C" that the section is again clear by giving the "Train out of section" dial signal, and leaves the needle of the block instrument in the "Line blocked" position. In the diagram the various conditions may easily be followed.

Relative Responsibility of Signalmen.

If we consider the functions of the two signalmen, we find that for traffic in one direction one of them is more responsible than the other. The signalman at the exit is the person who gives permission for a train to enter the section, and before doing so he must assure himself that

the conditions obtaining are suitable. Further, he must arrange for its disposal on arrival at his cabin, and see that it is in such condition as will justify him in clearing the section after it has passed out. The signalman at the entrance to the section cannot, under normal circumstances, authorise a train to proceed without having obtained the permission given by the acknowledgment of the "Is line clear?" signal, and the giving of the "Line clear" indication. Hence the responsibility for the authorised progress of the train rests with the signalman towards whom the train is proceeding. The signalman at the entrance becomes the guardian of the section, and must protect against the entrance of a train by the exhibition of the proper signals. For ordinary double-line working one signalman is, of course, the sender for, say, the up line and the receiver for the down line, so that responsibility is averaged for the total traffic.

If we carefully consider the relationship existing between the two divisions of apparatus, we find, as already stated, that the electrical is an auxiliary to the mechanically-operated outdoor signals, and exists for the purpose of perfecting arrangements for the safe dispatch of traffic between persons charged with its control, situated at considerable distances apart, for the purpose of indicating the condition of the line between those persons at all times, according to fixed conventions or rules, and for the notification of its passage from point to point. The safety of the system consists in the actions of all parties to the movement of traffic being synchronised, and as this most important point is only possible by the aid of the electrical equipment, its value as an adjunct is extremely great.

If we look over the requirements of the Board of Trade with reference to the electrical portion of the signalling apparatus, we are at once struck with their meagre character as compared with the requirements for interlocking. The first requirement reads: "The requisite apparatus for providing, by means of the block telegraph system, an adequate interval of space between following trains, and in the case of junctions between converging or crossing trains." Then, curiously enough, under the head of "Interlocking," we have: "The signal cabin to be commodious, and to be supplied with a clock and with a separate block instrument for signalling trains on each line of rails."

If we contrast the wording of the requirements with reference to the operation of the two classes of apparatus, we cannot fail to observe the great difference in the degree of precision in the language employed. Referring to the requirements with regard to interlocking, we find that the signalman "shall be unable" to lower a signal until after the points are set for the road controlled by that signal; that "it shall not be possible" for him to exhibit signals which will give rise to a collision; and that "he shall not be able" to move points connected with a line the signals for which have been previously lowered. There is no similar precision in the requirements for the electrical apparatus, the references being as already quoted: "The requisite apparatus . . ."; "a separate block instrument for signalling trains on each line of rails." Turning to the standard code, we find the general regulation to read: "All fixed signals must be kept at danger except when it is necessary

to lower them for a train to pass; and before any signal is lowered, care must be taken to ascertain that the line is clear, and that the block telegraph and other regulations have been duly complied with."

LIMITATIONS OF ORDINARY SYSTEMS.

If we consider the limitations of such a system of signalling as has been outlined, we find that its greatest weakness arises from the want of interdependence between the two divisions of apparatus. Theoretically, the arrangements are perfect; one signalman acts as a check upon the other in so far as they are both concerned in any operation, and the interlocking checks inadvertent error in the operation of the outdoor signals at either block station in so far as fouling routes are concerned. But neither signalman has a complete check on the actions of the other, and as the operation of the mechanical signals is in no way dependent upon the block instruments, the operations need not necessarily synchronise, and interlocking will not prevent following collision where operations of the signals may be repeated without check. The sending signalman depends upon the observation of the man at the exit of the section when the latter accepts the "Is line clear?" signal, and must necessarily do so; the receiving signalman relies upon the man at the entrance to the section not to send trains into the section without the usual acceptance and subsequent notice of the change of position of the train, but is powerless to control his actions; and both signalmen rely upon the due observance by the drivers of trains of the signals exhibited for their guidance. Hence there are three independent persons engaged in the movement and control of traffic, any one of whom by a dereliction from duty may be the cause of accident. Accidents caused by deviations from the regulations provided for their guidance have occurred frequently in each of the three conditions referred to, and a study of the Board of Trade inspectors' reports show that by far the greater majority of accidents to trains occur through the failure of one or other of the persons named to carry out his duties in the manner prescribed. Such failures are due, of course, to those temporary aberrations which, for want of more knowledge, we call absence of mind, but which seem inseparable from human existence. Carelessness, in the sense of deviation from regulations, there may be, but it should not be forgotten that men necessarily have other interests, other causes for thought, and that those most capable of concentrating their attention are always more or less conscious of other thoughts obtruding on their notice.

The object in contrasting the Board of Trade requirements with regard to interlocking with the less onerous stipulations for the electrical apparatus, is not to suggest that similar requirements should be imposed with regard to the latter. As a matter of fact, the railway companies have, generally speaking, been much in advance of th obligations, as will be seen when it is stated that, whilst the A Parliament making the block compulsory is dated 1889, and the re ments of the Board of Trade with reference to the Act are dat the decade during which the greatest progress was made in

the block was that of the seventies. Railway companies have spent enormous sums in equipping their lines with signalling apparatus, which, from the operating point of view, works well on the whole, and which, by the high degree of certainty that it introduces, has also contributed largely to speedy transit. Naturally, before scrapping their present apparatus and incurring the enormous expense which such a course would involve, they desire to assure themselves that any suggested change of procedure will have the advantages claimed for it. A well-known American signalling engineer some time ago said that absolute safety could only be assured by building a track for each train operated. The most rabid perfectionist would hardly desire to push his requirements so far as absolute safety if it is to be obtained at such a cost. Perhaps the American gentleman only desired to indicate that "absolute" perfection is unattainable.

Lock and Block.

The system of signalling considered is the manually operated and manually controlled, and its limitations have been referred to at some length. We may now briefly consider what suggestions are available for reducing the risks which experience shows have to be run from failure of the controllers. Generally, such systems are known by the not very appropriate or self-descriptive name of "lock and block," and they have as their object the union of the mechanical signals with the block apparatus, so as to make their operation interdependent, as far as consideration of the conditions obtaining may seem desirable. In this country systems have been devised, among others, by Sykes, Spagnoletti, Langdon, Saxby and Farmer, Tyer, Evans, and O'Donnell. Such systems, however, form at present but a very small fraction of the signalling apparatus in this country.

We have seen that the signalman at the entrance to a section may, with the ordinary system, send a train away without the concurrence or even the knowledge of the signalman at the exit. In order to prevent this, the signal controlling the entrance to a section is so interlocked with the block instrument at that end that it cannot be lowered to admit a train unless the man at the exit has given "Line clear," and so accepted responsibility. We know also that after sending a train away the signalman at the entrance may neglect to replace his signals to danger, and so, under certain circumstances, admit a following train. To prevent this, a complete lock-and-block system provides that a train, after passing the signal controlling entrance to the section, shall automatically put that signal to danger, and so protect itself if the signalman neglects to do so. Replacement of the signal lever in the normal position for danger results in it being locked by the block instrument, which prevents it being used again until another "Line clear" signal is given from the exit. We have also noted the fact that, ...h the ordinary system, the signalman at the exit can give "Train ...f section" for one train and "Line clear" for one following, quite ...ctive of the actual condition of the section, and before the first ...ut. To remedy this the instrument controlling the indications ...bins is arranged to lock itself by the operation necessary to

give "Line clear." This lock is maintained until the train so signalled has passed the signal controlling entrance to the next section, or has otherwise been disposed of. Hence we see that the operations of the signalman are cyclic, and are intended to be made in a given order. Further, we see that the operations of the signalman are checked on the points where risks of error exist in the uncontrolled systems.

Whilst the union of the signals and block instruments compels, under ordinary circumstances, cyclic operation by the signalmen, it by no means follows that the movements of all classes of traffic is, or can be, made in one unvarying order. Circumstances are constantly arising which necessitate deviation from the simpler routine of a block section, and means have to be provided to meet them. These are obtained by the provision of a "releasing key," by the use of which certain parts of the cycle necessary under ordinary conditions may be anticipated or dispensed with. The importance attached to the use of the release key may be gauged from the rules relating to its use for "cancelling," "obstruction danger," and "blocking back" signals, failure of rail contact, etc., and the special caution to signalmen "not to resort to the key until they are quite satisfied that its use is really necessary." Practically speaking, the provision of the releasing key is an acknowledgment of the want of sufficient flexibility to meet such cases as occur in the common operations necessary to the movement of traffic. As such, it is also an infraction of the automatic character of the system, and again saddles the signalman with the responsibility, under the ordinary system, of which it is the object of the lock and block to relieve him. Granted that the automatic character of any apparatus may be infringed for a legitimate purpose, and it ceases to be automatic. If use can be made of such apparatus under conditions that are suitable, there is nothing to prevent its use under misapprehension. If a misapprehension exists with reference to the conditions, no large-lettered cautions will prevent its use, as the signalman will be satisfied of its necessity, and recording use of the key in the train-book will not avert the consequences of the act. Instances have occurred where use of the release key under misapprehension has had serious results. Hence, whilst the lock-and-block is undoubtedly a step in advance of the ordinary system, it cannot be regarded as infallible, since in the use of apparatus provided to meet certain contingencies the signalman must exercise his judgment as to whether the circumstances absolutely warrant the course.

The type of rail treadle used in lock-and-block systems has the grave defect that it will clear a section behind it when under certain circumstances the line may not be clear. Such treadles are actuated to perform the release operation at the starting signal by the first vehicle passing over them, and so may clear a section by the first portion of a train which has become divided. Hence, although the block instrument would be released by the first portion of a train, and may again be used immediately, yet the signalman must personally assure himself that the whole train has passed, as he has to do in non-automatic systems.

In connection with the safety of such a system, we have with certain classes of instruments further to consider the effects that may be produced by contact between the block wire of either instrument and another working wire, and of the effects of atmospheric discharges. It is not the custom to build separate telegraph lines for the block circuits any more than it is not the custom to provide a separate track for each train operated. Line contacts, no doubt, still occur occasionally, and lightning protectors do not always protect.

Fog Signalling, etc.

It will be noted that the lock and block does not provide checks to obviate the consequences of neglect or inadvertence on the part of one of the persons concerned in the movement of traffic—the driver. He is left altogether out of consideration, and must rely upon himself for due observance of the signals exhibited for his guidance. Yet the driver is probably the most important of the persons concerned, since he is the actual controller of the means of movement of traffic, and is the last link in the chain of checks imposed by signalling systems. Whilst accidents have taken place from disregard of signals in clear weather, the duties of drivers are most onerous during fogs or snow-storms, which obscure the sight of the signals by which they are guided. Under such circumstances the visual signals are supplemented by explosive signals directly operated by the passage of trains over them. The detonators, which are placed on the rails in the neighbourhood of the signals by hand, by men specially collected for the purpose when such signalling becomes necessary, are the danger signals, but they are supplemented by signals with hand lamps, for which the drivers and firemen must watch. The signals themselves are operated by the signalmen in the usual way, and the fog-signalmen act in accordance with the positions of the signals from time to time. Whilst a signal is at danger the detonators must remain on the rails; when the signal is off they are removed. The off position of a signal which cannot be seen is therefore indicated to a driver by the absence of an explosion, and the hand-lamp signals.

Such a system is most expensive to the companies, entails considerable exposure and hardship upon the fog-signalmen, and suffers from defects of a practical character in operation. The collection of the men for fog signalling occupies some time, as they have to be withdrawn from other duties, or to be brought from their homes. The person who has to decide upon the necessity or otherwise of commencing fog signalling is not the person most vitally concerned, or who has effective control of the movement of the traffic affected. Fogs are sometimes of a deceptive character, and appear differently to a man on the foot-plate and another on the ground, and they change in intensity very rapidly on occasion. The "All right" signal is partly of a negative character, in that it is given by the absence of explosion, together with the hand-lamp signals. The latter signals may or may not be seen by a driver or fireman. Sight of such signals involves either continual concentration for the purpose, or the ability to localise positions so as to be able to look specially for them at the proper time.

This question of localisation of position is of some importance. Experienced drivers, of course, know the "feel" of the road perfectly well, and localise their position from a large number of local circumstances, such as the passing of (over and under) bridges, curves, cuttings, signals, cabins, stations, etc., all of which "talk" to them. Whilst this is the case at ordinary speed the indications are not so plain at lower speeds, and, moreover, approximately the same indications may be met with at different parts of a journey. Hence, taking all things into consideration, the present system of fog signalling leaves something to be desired.

Attempts have been made to place the operation of the fog signals in the hands of the signalmen, but whilst such methods enable the system to be brought into use more promptly than when hand signalling is resorted to, and obviate hardship and exposure to the fogmen, it does not alter the character of the signal, and, moreover, it does not allow of personal supervision, and abolishes the supplementary hand signals. Probably the most promising systems for superseding the ordinary fog signalling are those which provide for the signal being given directly upon the engine itself, and for it to be in constant operation. There is quite a large number of such systems available now, but taking the whole country into consideration their adoption is not proceeding at a great rate. Some of the systems referred to are mechanical, such as that devised by Mr. Raven, of the North-Eastern Railway, and which is being fitted to a large number of the company's engines; others are partly mechanical and partly electrical, as Mr. Brierley's system, which has been introduced by Messrs. Saxby and Farmer; others again are wholly electrical, such as the method of signalling devised by Lieutenant-Colonel Bolitho. The majority of such systems operate by means of an obstruction working in conjunction with the signal to be indicated, placed on the line, which gives an alarm on the engine, and so calls attention to the position of the signal, In Mr. Raven's system the alarm is a special whistle which may be operated by steam or compressed air. In Mr. Brierley's and Lieutenant-Colonel Bolitho's systems attention is drawn by means of electric bells and discs, and electric bells, respectively, carried on the engine. In the latter the electrical circuits are closed by contact with steel brushes placed on the line side in a similar way to that previously used by Mr. Burns and others. In some of the systems an alarm when the signal is "on" is considered sufficient; in others, again, provision is made for repeating both the "on" and "off" positions, so that the signal is positive in both cases.

It is, of course, impossible to enter into a detailed description of such systems, or even to enumerate all of them. Mention, however, should be made of the system devised by Mr. W. S. Boult, in which necessity for contact between parts of moving vehicles and obstructions on the line is obviated. This is done by the use of permanent and electro magnets placed on the line, the latter being operated in conjunction with the signals. The magnets act upon polarised relays carried upon the engine in such positions as to pass immediately over the former, and the relays operate appropriate circuits for the purposes

required on the engine. The indications given on the engine are visual (miniature distant and stop signals, and numbered and coloured discs) and aural (bells). The system distinguishes between "on" and "off," between "distant" and "stop" signals, provides route indicators to show on the engine which road has been prepared at junctions, is capable of repeating the signals in the cabins, and is self-testing for both engine and line circuits. Failure of the line or engine circuits also results in the danger signal being given at the next signal approached after the failure, and partial failure of the latter circuits is distinguishable. One special feature of the system lies in the fact that the last indication received on the engine remains until the next signal is reached, and so serves as a continual reminder of the conditions under which the train is running. This result is not obtained with the present system of visual signalling, and its value in a case where a driver has failed to comply with the signals exhibited is obvious, whilst the ability to distinguish between distant and stop signals is a valuable characteristic for purposes of localisation. The indications given upon the engine are of the most positive character, the semaphore arms being first thrown to "danger," after which they either remain in that position if the actual signal is "on," or are immediately lowered if the signal is "off." The system is of the most complete character, and its design shows the closest study of the conditions to be met, whilst the details of the apparatus are most ingenious and at the same time very simple. Its adoption would revolutionise the method of signalling, since practically there would be no necessity for providing the mechanical signals now in use.

The selection of a system of auxiliary signalling such as has been considered has a business aspect, as well as the technical and operative sides. In order to get the utmost value from such a system, it should, since engines run over other companies' lines than their own, be uniform for all lines if possible, or at least for the lines over which interchange of locomotives takes place. Some companies might be able and willing to pay more for the additional security to be obtained than others; and some, again, might consider certain precautions essential which to others might appear to be superfluous, or not worth the cost of obtaining. The matter is one for common agreement amongst the companies running over each other's lines. Otherwise, the subject is likely to prove a worthy successor to the position so long held by proposals to supersede the cord communication by electrical means—a matter for wordy debate to be settled eventually by the adoption of other means.

"Automatic" Signalling.

Summing up the situation as it appeared to him in 1898, the present speaker wrote: "Railway signalling appears to have now reached a stage at which some departure from the present methods seems probable. The lines upon which changes will be made will, in all probability, result in a greater degree of automatic control than obtains at present." The indications at present seem to confirm this view very strongly, and we appear to be likely to see early changes in

the methods of signalling of the most radical character. The American "track circuit" system is gaining a footing in this country, and if it should be found suitable for a country where junctions are so numerous and near together, and where the great bulk of traffic is between points comparatively near to each other, a revolution will be effected which will at once change the whole character of signalling in this country. And there is no more reason to doubt that the success of such a system will result in financial relief to the companies than there is to doubt the necessity for such relief.

In this country there is already an installation of automatic signalling in operation between Grateley and Andover, on the London and South-Western Railway, in which the signals are actuated by air on the low-pressure system, the movements being controlled by the positions of trains on the line, which is formed into track circuits. The North-Eastern Railway Company has also made arrangements with the Hall Signal Company of America to equip a portion of their main line to the North, between Alne and Thirsk, with a track circuit system of automatic operation. This installation will differ from the ordinary Hall system—in which the signals are operated by electric motors—and from the London and South-Western Company's installation, in that the signals will be self-contained as regards motive power. Movements will be made by carbonic acid contained in steel cylinders at a pressure of 600 lb. per square inch, the working pressure being 50 lb. As many as 10,000 movements can be obtained before it becomes necessary to recharge. At the junctions between Alne and Thirsk the automatic signals leading to fouling points with the branch lines will also be under manual control, so as to admit of branch working. Such cabins, however, will be closed at times when the branch traffic ceases. The sections will be shorter than ordinary. Siding points connecting with the main line in the purely automatic sections will be provided with indicators communicating with several of the rear sections to show whether trains are approaching before the switches are opened for the siding. It is expected that a considerable annual saving in the working expenses for the signalling of that portion of the line will result from the change, and if this is effected and the system is otherwise satisfactory, no doubt further extensions will follow in the near future.

Taken on the whole, railway signalling in the States is of a very mixed character, and varies from the antiquated "train dispatcher" system, with or without telegraphic communication, through the telegraphic, the manually operated, manually controlled, and the controlled manual, to the automatic systems. There is not time here to discuss these systems, or the many other interesting details of American signalling, such as, for instance, the relative advantages of the "normal clear" or "normal danger" positions for signals; two or three position signalling; track sections *versus* treadles for the controlled manual; the simple single signal, the overlap, or the home and distant systems; the operation of signals by electricity or air, and high or low pressure for the latter; track batteries and relays; the bonding and insulating of rails; and other matters of a very practical character. The auto-

matic system seems to have taken firm hold, and when we consider its advantages as looked at in the States, there seems to be little cause for wonder that it has done so, especially in a country where long continuous runs between diverging points are common. The reasoning adopted is very plain, as the following quotations from a series of articles in the *Electrical Review* last year will show: "If the substitution of automatic devices for the control of a system formerly under human control and operation (the controlled manual is being referred to) produced such beneficial results, why, one naturally asks, should not the introduction of automatic mechanisms for its operation produce like benefits." "It"—the automatic system—"is constantly on duty, requires no relief substitute, never goes on strike nor tires of its job, never sleeps, gets drunk, or deserts its pals, and never misconstrues orders." "The ideal system is one in which the train in a block has control of the signals governing the entrance to that block." "The system affords means of detecting misplaced switches in the block, of failure of cars on a side track to stand clear of the running line, has frequently detected broken rails and obstructions in switches, it affords opportunity for trackmen to protect blocks during emergencies, and for protection during repairs." "Operators for such a system are superfluous, and could only be of use in case of derangement." "Railroad officials are universally awakening to the possibilities of automatic signals, and that wages are better utilised in obtaining automatic operation."

Another advantage claimed for the automatic system is that the carrying capacity of a line may be increased from the facility with which the block sections may be shortened. On this subject, however, the last word is not with the signalling systems, since the lengths of the sections must always be such as to allow any train, whatever its speed, weight, and braking power, to be brought to a stand in the space allotted. The suggestion, moreover, involves a levelling of speeds, which again will require limitation of loads for mixed traffic, since the standard of speed will always be set by the fast passenger traffic. There is no tendency ascertainable in either of these directions at present.

Further study of automatic systems shows the great necessity for supplementary signalling under exceptional circumstances, such as fog or snow, since there is no personal supervision. Some form of apparatus giving the signals on the engine would seem to be imperative.

Where automatic signals are in use, the rule that a stop signal shall not be passed when in the danger position unless other signals are given which are recognised as superseding it, must necessarily be abolished, and a time limit of detention at the signal imposed, after observance of which the train goes cautiously forward until ordinary signalling is resumed in the sections ahead. Unless special regulations or provisions are made, and in the event of prolonged operations at a point giving access to the main line, this may result in a train arriving at the signal actually protecting a train drawing on to the main line, when, of course, the space limit will not be observed.

In the States, it is usual to distinguish signals which may be passed at "danger" after a time interval from those which, being under manual control, may not be passed without special instructions. Where signals are at one period automatic and at another under manual control, the conditions are more complex.

Possibilities of Signalling with Electric Traction.

We have seen that the adoption of human control for railway signalling has necessitated the imposition of numerous checks upon the actions of the controllers, and has required considerable auxiliary apparatus for a variety of purposes. The adoption of automatic signals dispenses with all the costly apparatus referred to, except at junctions where, owing to the want of selective properties, automatic systems are unsuitable. The question for consideration now is, "Is the automatic system, as described, final?" If we consider the present outlook with regard to railways, we find that we are probably on the eve of a very great change in methods and even routine of transportation. The great question to be now decided concerns the use of the self-dependent locomotive, or, as an alternative, the use of locomotives taking their power from their locality, wherever that may be, in the line of their run. The question is not entirely confined to steam and electricity, although at present these two are the only ones worth considering. As all are aware, the railway companies are taking action in consequence of the incursion of the electric tram into what has hitherto been practically a monopoly. The directors of the North-Eastern Railway are considering tenders for the equipment of part of their lines in this neighbourhood for the use of electric power; the Lancashire and Yorkshire have partly completed their arrangements; the London and North-Western are said to be considering the question; and the Great Eastern are to apply for powers for the same purpose as early as possible. The proposals now being put forward are for comparatively short-distance suburban traffic; the electrification of long-journey main lines is not just yet.

The point for consideration here, however, is not the suitability or otherwise of electric traction, but the effects that it may have on signalling. If we look over the principal equipments of a train, we find that we have steam for locomotion; gas, oil, or electricity for lighting; and pneumatic appliances for braking. Electricity is capable of displacing all these for each of their several purposes. As electrical power is delivered to the locomotives from the outside, we have presented to us conditions which have no precedent, and opportunities for outside control such as have never before existed. Hitherto the driver has been the sole actual controller of the means of locomotion, and short of throwing the train off the line, or into a dead end, no other person could affect the results when he neglected certain duties. With electricity all this is altered, and we have to deal with an agent which is easily handled, and lends itself readily to automatic or other control and operation. American automatic signalling gives control of the signals to the train requiring their protection. Where

supplementary signalling is in use to check error on the part of the driver, its design is generally with a view to direct action on the control of the motive power, rather than to call attention to a dereliction of duty, as with us. With electric traction there should be no difficulty in arranging to give such direct control to the train which requires to be protected by cutting off the power from all sections that would endanger its course, whether these are "following," "converging," or "crossing." Signals as now used would then be superfluous, except at such places as those where selection of traffic rendered them necessary. Control of the motive power is a far more effective check on inadvertence than any other that can be devised. The whole aim of the signalling now in use on railways is to control the man who controls the motive power. If we can give to a train the means of controlling the motive power to other trains, which may be sources of danger to it, the men who control the motive power on those trains will no longer count in connection with the subject under notice. After all, automatic signalling, as described, does no more for the driver than the manual or the controlled manual, if as much, since it removes the personal supervision now provided, which is not *always* faulty, and has on many occasions been of the highest possible value.

The author's thanks are due to Mr. Raven, of the locomotive department, and Mr. Ellison, the superintendent of the telegraph department of the North-Eastern Railway, and to Mr. Fletcher of the L. and N.W. Railway, for the loan of apparatus for use at the meeting.

Mr. Heaviside.

Mr. A. W. HEAVISIDE said that, with regard to Mr. Pigg's paper on "Railway Block Signalling," they were certainly obliged for such an exhaustive statement of what is done in this direction at the present time, which is a very critical one in the history of block signalling. He was one of a party which recently visited Tyne Dock to see the system in operation there, and it occurred to him that the capital cost was very considerable—rather more than the ordinary system. He did not see why they should not do the whole thing electrically, and not use pneumatic power at all. If a man were to commence to build a new railway at the present time, he did not think it likely that he would proceed on the same methods as the existing arrangements. The old system requires a great deal of maintenance. Mr. Pigg had said that the North-Eastern Railway Company had employed the telegraph and the telephone as an auxiliary, and he would be very glad to hear more about his experiences with the telephone. There were many other interesting questions which might be raised, but in the absence of Mr. Pigg it was rather difficult to carry the discussion much further.

Mr. Moir.

Mr. A. MOIR said that, while asking for more seemed rather ungracious, seeing the paper was so long and exhaustive, if Mr. Pigg had been there he would have liked to have asked him what the resistance of the block coils is which they use on the North-Eastern Railway, how many amperes were required to actuate the instruments, what sort of primary battery did they find gave best results; also whether secondary cells have been employed with any success

Mr. Longman.

Mr. R. M. LONGMAN: With reference to Mr. Pigg's statement that no passengers lost their lives in 1901, it may be added that many fatal accidents occurred at highway level crossings, due in many cases to carelessness or forgetfulness on the part of the gatemen, who often open their gates without placing their signals against the trains. A little interlocking device would thus save many lives.

Mr. Pigg.

Mr. J. PIGG (*in reply, communicated*): I regret that a misunderstanding and my recovery from an illness led to my absence from the meeting of January 19th and have further prevented a full discussion of the problems to be met with in railway signalling. There can be little doubt, as remarked by Mr. Heaviside, that the capital expenditure for such a system as he inspected is greater than that for the ordinary system; but if a commensurate saving is effected, either in labour or by facilitating the operation of traffic, the increased expenditure will be justified. Whether such a saving will be shown remains to be seen. The period of use is at present too short to enable a reliable opinion to be formed. It must, moreover, be remembered that the maximum economy is not to be expected from such a system in small isolated installations with separate equipments for motive power.

The employment of the telegraph and telephone in connection with the operation of railway traffic is, as stated, auxiliary to the ordinary block signalling, and does not differ materially from the methods of using such instruments elsewhere. They are not used *directly* in block signalling, but for perfecting arrangements before traffic is allowed on the line, or for giving information beyond the scope of the code, or for communication between block points not directly connected for signalling purposes. The telegraph is used for transmitting notice of the times trains leave or pass certain points to other places on their routes, so that proper arrangements can be made for dealing with them without unnecessary delay to other traffic. The telephone is used for similar purposes, but more locally and over less extended distances; although valuable auxiliaries for the working of traffic, they are not, of course, part of the block system proper.

With reference to Mr. Moir's questions, the block indicators in use on the North-Eastern Railway are wound to a resistance of about 150 ohms. The batteries used are the ordinary porous-pot Leclanché cells. A six-cell battery is used for the pinning instruments, and a four-cell set for the non-pinning. (Since the reading of the paper the North-Eastern Railway has ceased to use the block indicators in connection with the code, and no doubt the non-pin batteries will be dispensed with.) I have no idea of the minimum current required by the block indicators. On the North-Eastern Railway they work perfectly well with ten milliamperes, but they are never intentionally worked with the minimum.

Secondary cells have not, to the writer's knowledge, been tried anywhere for block working, and the prospect of their adoption does not seem very great. The first cost and maintenan[illegible] [illegible]f such cells would seem to be necessarily greater than that of p[illegible] [illegible] cells, and the amount of apparatus in the average signal cabin l[illegible] [illegible]lls for the adoption of the universal battery system which th[illegible] [illegible]ge cells

Mr. Pigg. so greatly facilitates. Moreover, such a battery arrangement is for railway signalling an operation of the nature of putting too many eggs in one basket. It is desirable that the signalling of the different lines should be as independent as the lines themselves are for the operation of traffic.

There is a certain amount of truth in Mr. Longman's remarks respecting accidents at gate crossings. Accidents do occasionally occur at such places, but although the writer has mixed intimately with gatemen over a considerable area of this country, and although he pays great attention to the reports of the inspectors of the Board of Trade, he would not go so far as to say that they *often* open their gates without placing their signals against the trains. There are many cases in the writer's own knowledge where signal cabins are erected at highway crossings solely on account of the traffic on the road. In these and in all cases where the gates and signals are worked from one point the gate-wheel is interlocked with the signal levers. In others cases a dwarf frame is provided which affords the interlocking referred to. At gate crossings between block points many companies provide electrical apparatus, connected in the block circuits passing the gates, by which the gateman is constantly aware of the condition of the line on both sides of his gates.

LEEDS LOCAL SECTION.

MOTIVE POWER SUPPLY FROM CENTRAL STATIONS.

By R. A. CHATTOCK, Member.

(Paper read at Meeting of Section, February 19th, 1903.)

The development of a supply of electric energy for motive power to private consumers has been occupying the attention of Central Station Engineers for a considerable time, and, during the last two or three years, has been stimulated very much by the excellent results that have been obtained in several large towns. It is obvious that, given a large network of mains that has been laid for the purpose of supplying lighting consumers, it is to the interest of these consumers, as well as of the authority responsible for the supply, to have as much current as possible distributed through it, especially during the hours of daylight. The lighting consumer benefits by the greater output combined with the increased load-factor at the generating station, making it possible to generate current at a cheaper rate. The supply authority benefits by being able to reduce the cost of supply and by having the demand for current stimulated. The standing charges on the cost of the mains are spread over a greater output and so reduced proportionately.

Direct-current stations, so far, have done most in developing this branch of the supply. This is probably because the direct-current motor has, up to recent times, been more easily applied to existing conditions, and has proved a more reliable and efficient machine than the single-phase alternating-current motor. Now that alternating-current stations are changing over to, or putting down, auxiliary, two- and three-phase plant, this disadvantage should disappear, and the engineer in charge of such a station should be able to follow in the steps of his direct-current brother.

It may be interesting to give a short description of what has been done in connection with a supply of current, for motive power, by the Corporation of the City of Bradford. The supply is by means of direct-current, the voltage being 230 or 460. The first motor was connected to the mains in 1891. There was not much development until 1897, when the Corporation inaugurated a system of hiring out motors, and at the same time reduced the price for current to 2½d. per unit. In 1896 the percentage of current sold for motive power to the total output was only 6·7 per cent. This percentage has rapidly increased as the facilities provided for obtaining motors have been realised and appreciated by the public, and as the charge for current has been reduced to the existing rates of 2d. for intermittent use, and 1d. for continuous use, until, in 1902, it stood at 49·25 per cent.

The gradual increase in this branch of the supply is set forth in the following table, which also shows the improved load-factor of the generating station.

	Year.			
	1893.	1896.	1901.	1902.*
Motors on the Supply, Dec. 31st. On Hire	—	7	525	641
Motors on the Supply, Dec. 31st. Not on Hire	26	58	229	272
Motors on the Supply, Dec. 31st. B.H.P. ...	110	244	3,460	4,398
Units sold for Motive Power	19,346	54,972	1,297,120	1,899,873
Total Units sold to Private Consumers	480,494	813,623	3,012,158	3,857,757
Percentage of Motor Units on Total Units...	4·02	6·76	43·06	49·25
Price charged per Unit for Motive Power...	4½d.	3½d.	2d. & 1d.	2d. & 1d.
Average Price per Unit obtained for Motive Power	4·5d.	3·5d.	1·20d.	1·17d.
Load Factor, excluding Traction, per cent.	3·13	8·93	11·74	13·78

* The figures for 1902 are approximately correct.

During these years it has been possible to reduce the charge per unit for current supplied to the lighting consumers from 6d., in 1892, to 4½d., less 2½ per cent. discount and a free supply of incandescent lamps, in 1899. The price has stood at this figure up to the present date, but the Corporation anticipate that they will be able to reduce it still further in the near future.

In calculating the cost of generation of a motive power supply, when this is combined with a lighting supply, the following points must be borne in mind:—It is not necessary to increase the staff of men employed in the station beyond what would be required for a pure lighting supply. The management expenses, rents, rates, and taxes remain the same. The plant installed in the generating station has to be increased only very slightly, owing to the fact that the main part of the motive power supply is discontinued at 5 p.m., before the peak of the lighting load has to be met; the part that does overlap, can be safely and most economically dealt with, by slightly overloading the station plant, for half an hour a day, for about six weeks during the twelve months. The question of black fogs, of a density sufficient to necessitate a supply during the hours of daylight, equal to the maximum lighting load, has very rarely to be considered, so rarely that it really only affects one or two towns in the country. A fog such as is ordinarily met with will not create a demand for more than 75 per cent. of the maximum lighting load, and it is found in practice that the motive power supply can be satisfactorily dealt with by the plant installed.

The same considerations apply to the question of extending the distributing network of mains. It is found that the majority of motors installed, are connected to the existing network, which has been laid for the supply of lighting consumers, and the current used by these motors helps to utilise the mains during the hours of daylight. This is a set-off against any small extensions that it may be necessary to make to supply outlying power consumers. In some cases, however, considerable extensions may be necessary; these should be considered separately, and if the estimated revenue from the current supplied does

not equal a certain percentage on the cost of the extension, the application should not be entertained, unless, of course, the applicant is willing to pay such a sum towards the cost of the extension, as will make it remunerative.

The minimum percentage on the cost of an extension, that it is policy to require, must be different in different towns, and can only be ascertained by experience. As a basis to go upon, a percentage of 10 per cent. is suggested, this figure having worked out satisfactorily as regards the City of Bradford.

It may be safely assumed, therefore, that the cost of generation should not be estimated to include the following items :—

Wages in Generating Station.
Management, rents, rates, and taxes.
Standing charges upon the outlay in respect of station plant and distributing mains.

The items which should be included are as follows, and these should be taken at the full rate per unit for the whole of the supply :—

Coal.
Water.
Oil, stores, etc.
Repairs and maintenance of plant and mains.

Turning now to the considerations affecting the price to be charged. It has, during the last four years, been the practice in Bradford to charge one penny per unit for motors used continuously throughout the working hours of the day, and twopence per unit for those used intermittently. This method of charging has answered fairly well, though it is open to several objections. For instance, some power customers who use their motors intermittently consume a much greater number of units per horse-power installed than others who have motors running continuously ; again, it is often very difficult to decide whether the use of a motor is intermittent or continuous.

The maximum demand system of charging is not so applicable to motor supply as it is to lighting supply, on account of the fluctuating nature of the load on a motor, and of the liability to sudden heavy overloads. The effect of these overloads is not necessarily felt by the generating station at the peak load time, but the reverse of this is rather the case.

It would seem that the best method of charging is to base a sliding scale charge per unit upon the number of units used per horse-power installed per half year. Such charge might be graduated at 1d., 1½d., 2d., and 2½d.

It is found that compared with a gas engine using gas at 2s. 3d. per 1,000 cb. ft., the cost of running a motor at 1d. per unit is considerably less, in some cases the cost is half that of gas, in others the cost is approximately the same. This, however, is owing to the motor being set to drive long lengths of shafting where the load is fairly continuous and heavy, an ideal drive for a gas engine. Where the load is subject to great fluctuations, as is the case with crane and hoist driving, the

motor, even at 2d. per unit, shows a great saving over the gas engine. This is owing to the facility for stopping the motor when not actually in use, and starting again when required. It is found that this cannot conveniently be done with a gas engine.

In order, therefore, to show a saving over gas at the above figure per 1,000 cb. ft., the charge for current should vary from 1d. to 2d. per unit.

The amount charged for rental should be kept as small as possible consistent with paying actual expenses, and any profits required should be looked for from the sale of current and not from the receipts for rental.

The rental should include the following items: –

Interest upon capital cost of motors and other apparatus.
Cost of inspecting motors periodically.
Cost of maintenance of motors due to fair wear and tear.
Cost of depreciation on motors.

In the City of Bradford, for the year 1902, the cost of inspection and maintenance of motors on hire amounted to £1,723, the H.P. of the motors on hire being 2,996.

It would appear that an amount of 15 per cent. on the capital cost of apparatus is sufficient to cover all liabilities in connection with a hiring out department, and to allow sufficient margin for depreciation.

In conclusion, it is hoped that the figures and suggestions given in this paper may be of interest to Central Station Engineers. They are based upon actual experience in connection with the Bradford Corporation supply, and should prove useful, especially to those Engineers who are contemplating a motor-hiring department.

Mr. Mountain.

Mr. A. B. Mountain said that he agreed almost entirely with Mr. Chattock. He was of opinion that a supply of 4,398 H.P. for motors was larger than the supply in any other town in England, and the author would no doubt say that the great success at Bradford was due to the fact that this city had a large number of small trades.

Regarding the single-phase question the speaker thought that Mr. Chattock was a little late in his criticism; if he had made this remark three years ago most people would no doubt have agreed with him. In England there were about one thousand manufacturers of continuous-current motors, but few of them make single-phase, and, probably, fewer still two- or three-phase motors. There were thousands of persons criticising single-phase motors and advertising continuous-current, but he did not think that it was wise for them to allow themselves to be carried away. They had, rather, to think of what was really right and suitable. He disagreed with Mr. Chattock on this point very strongly.

Referring to the percentage (10 per cent.) allowed by Mr. Chattock on the cost of an extension, he thought that there must have been an oversight here. He did not consider that 10 per cent. would cover the cost of the extension for mains, unless, of course, there were very special consumers.

Further, he did not think that the author had sufficiently brought out the great advantage of electric motors over gas engines. There was no doubt that, by getting rid of shafting, the power required in a place was enormously reduced. For example: In a small works that he recently visited they used to have a gas engine of 16 H.P., but they now find that five H.P. in motors put on different machines would do precisely the same work. Mr. Mountain.

Mr. G. WILKINSON said Bradford was a pioneer town in electric lighting and certainly showed the way in promoting the sale of electricity. Like the previous speaker, he was very much struck with the second paragraph of the paper. It showed that Mr. Chattock had a certain amount of pity for the community which has to put up with single-phase motors. He himself did not share that sentiment. In the first place he would like to point out how very much more reliable they were than direct-current motors. Taking into consideration the fact that the revolving part simply consisted of a mass of iron with short-circuited conductors, the advantage certainly rested with the single-phase machines so far as reliability was concerned. The great drawback at present, admittedly, was the want of a simple method of varying the speed of single-phase motors. He had used this type for hoists, cranes, printing machinery, and the like, and had found them very successful. Mr. Wilkinson.

Mr. Chattock had stated that the load factor in Bradford, excluding traction, was 13·78. He presumed that this did not represent power, but was simply the load factor relative to the motor business. From the amount of the horse-power supplied, he thought that in Bradford many of the motors were small.

Concerning the supply of electricity for large powers except for intermittent work, there was a very formidable rival in oil engines. Mr. Chattock gave a comparison between electricity at 1d. per unit and gas at 2s. 3d. per 1,000 cubic feet, but he did not mention anything less than 1d. per unit for electricity. There were English oil engines made which would give 5 or 6 H.P. for an hour for 1d., and there were German engines, one of which he had under his control, working daily for practically 16 hours, giving 9 B.H.P. for 1d. per hour. They required a certain amount of labour and attention, but they had many advantages. In the future we should have very keen competition from oil engines. There were now firms ready to enter into contracts to supply any quantity of oil as fuel at 35s. a ton.

With reference to the extension of mains in Bradford it appeared that the charge was upon a basis of 10 per cent. on the capital outlay. The paper did not indicate whether this was an annual charge or whether it would run out when the interest and sinking fund expires. It seemed to be a very reasonable figure, but further information was desirable. Again, consumers who used their motors intermittently appear to consume a much greater number of units than did regular users, and it appeared that they must therefore have motors too large for the work they have to do.

He quite agreed with the sliding-scale method as an equitable means of charging for power, and was quite gratified to find that 15 per cent. was sufficient to cover the cost of a hiring-out depart-

Mr. Wilkinson. ment, and thought it very reasonable and a charge that any consumer could afford to pay.

Mr. Fedden. Mr. S. E. FEDDEN said that he could join issue with the author in regard to single-phase motors. He had installed motors up to 80 and 90 H.P., and lately one of 160 H.P., although he thought it most likely that two-phase motors would be necessary for heavy work. He had, however, no intention of abandoning single-phase working altogether for small motors on present single-phase mains.

With regard to the question of variable speed he had never found any demand for it.

They were in Sheffield following on much the same lines as in Bradford, as they had in 1900 only 20 motors; in 1901, 71; in 1902, 109; whilst this year they had 220, which amounted in all to 1,400 H.P.

With regard to the price of energy, they had always had in Sheffield a charge of 4d. a unit for lighting. Three years ago it was 2d. a unit for power, and they then offered consumers 1½d. per unit, but nobody would look at it. Finally they arranged to charge all-day consumers 1¼d. per unit, with a 1d. per unit for all-day-and-night consumers. If they used sufficient units to make up 50 per cent. of the horse-power installed, they allowed them to come in at the 1¼d. rate. Gas being only 1s. 6d. per 1,000 cubic feet, they had very keen competition.

He encouraged the laying of mains, but did not put on any price or percentage, for the reason that the local price of gas was so low, and their mains were past most of the houses and works. Referring to the cost of generation, Mr. Chattock stated that rates and taxes should not be included, but he thought that a certain percentage of these charges, and also some standing charge on the distribution of the mains, should be added to the cost of the unit in addition to the items mentioned. He was rather surprised to see the figure given for the maintenance of motors. The cost of maintenance appeared to work out at about 11s. 6d. per H.P. in Bradford. The motors averaged 4·7 H.P. each. The cost of maintenance and inspection in Sheffield came to £75 for the whole of the motors, or about 3s. per H.P.

He had not yet had the pleasure of a burnt-out armature, but was looking forward to it.

Mr. Churton. Mr. T. H. CHURTON said that he had had an opportunity of making a comparison of electric driving and gas-engine driving. In his works he had a 6-H.P. Crossley engine and found that, at full-load, the cost was little less than ½d. per H.P. hour, and at normal working load it was about 1d. per H.P. hour. It was necessary, with a gas engine where there was a variable load, to have an engine of considerably greater power than was generally used, but in the case of a motor it was not so. If a gas engine were overloaded it would pull up, but a motor could be overloaded to a very much greater extent, before it will stop, especially if it were a two- or three-phase machine. In his case a two-phase motor was actually costing him less than the gas-engine did, although gas in Leeds cost only 2s. 3d. per 1,000 cubic feet. Unfortunately there was no convenient way of starting single-phase motors, and a method of starting was required which gave really no trouble.

As touching the competition between electric driving and oil engines, it must be noted that motors could be placed where it would be impossible to fix an oil-engine and there was also too much work involved in the use of oil engines, to say nothing of the smell and noise. Mr. Churton.

Mr. V. A. FYNN thought the single-phase motors were not entirely satisfactory. He had been familiar with them since 1893, when they came out, and although he liked them, and was greatly interested in their working, he did not think that they answered the present requirements. In cases where only a few small motors were connected to the supply mains, the power-factor question did not matter very much. If, however, one were concerned with large powers, the matter became more serious than was generally believed. At the Frankfort Exhibition of 1891 a motor was actually shown which had a power-factor equal to unity, although nobody seemed to have taken any notice of it. The principle which was used in that motor he had lately employed with various alterations and improvements in order to obtain a power-factor equal to unity in a single-phase motor of his design which he was bringing out, and which besides having a very great starting torque, gave promise of the possibility of regulating its speed. A 3 B.H.P experimental motor had been completed which started with a 10½ H.P. torque and with a current simply proportional to the full-load starting current. Mr. Fynn.

Mr. W. EMMOTT said that Bradford had been worked for all it was worth with regard to motors. He could not speak from the Municipal Engineer's point of view, but only from that of the Consulting Engineer, and he thought it was a good lesson for some of the smaller stations. Much depended upon the kind of man who was in charge of a motor department. He considered that with a gas-engine running up to 10 or 12 H.P. it was cheaper to put in motors at 2d. per unit. He also thought that 15 per cent. was a large amount for maintenance. For himself he thought 12 per cent. a fair and ample amount. He gave some tests of the low thermal efficiencies of gas in various towns which he had experienced, but as the gas companies were under no obligation to supply gas for power purposes, the consumer had no remedy. This accounted for the large gas consumption per B.H.P. which he had noted in many cases, and was all in favour of electro-motors. Mr. Emmott.

Mr. W. M. ROGERSON thought that consumers using lifts and cranes intermittently, say not more than half an hour at a time, should pay more than consumers using power continuously. Mr. Rogerson.

Mr. H. DICKINSON (*Chairman*) did not agree with Mr. Chattock that it was unnecessary to increase the staff or plant for the full load. If the overlapping motor-load grew larger than the lighting load, he would have to put in additional plant to keep up with it, and consequently the staff would have to be increased accordingly. Mr. Dickinson.

Regarding the extension of mains, on a basis of 10 per cent. of the revenue he thought this very small, and remarked that he would go into some districts for one per cent., but not into others for ten per cent. if there were no prospects; therefore some little reservation was necessary on that point. The consumers around the Works were made

Mr. Dickinson. equal to consumers in the outlying districts, unless there were a very big margin between the selling prices. At Leeds they were selling at cost price, as, last year, on a capital of £500,000, they made a profit of only £3,000. He did not think he could afford to run to outlying districts on a bare 10 per cent.

Referring to the units per B.H.P. for last year at Bradford, which worked out at about 450 for every H.P. installed, he should like to ask what sort of users they had, because these figures did not at all correspond with those for Leeds. It was there found that they were getting 800 units per H.P. installed. He did not know whether these motors were for hoists, but he thought that Leeds seemed to be in a very favourable position. In 1901 there were 205 H.P. installed; 1902, 685 H.P.; and there were now 1,363 H.P. The price in 1901 was 2d., less 5 per cent., and in 1902 it was 2d. to 1⅛d. on a varying scale. If the units were less then 360 per H.P. it was 2d., and on to 720 units per H.P. installed. The average price obtained for motors was 1¼d.

There were another 400 H.P. awaiting connection, and an application for 500 H.P. to drive a rolling mill had been received.

Mr. Chattock. Mr. R. A. Chattock, in reply, said that he had not had much experience recently with single-phase motors, but he had had a good deal some time ago. He thought that the motors ran at a very excessive speed, owing possibly to the high frequency that was in general use, and that the efficiency of the motors up to about 10 H.P. was nothing like that which could be obtained from direct-current motors. Commonly the starting current was excessive, and affected the general supply in the neighbourhood, which was a very great objection.

He was surprised to hear that Mr. Fynn and Mr. Fedden thought that there were single-phase motors which would beat direct-current motors.

The phenomenal increase in Bradford was not due to any special advantages; Bradford was an ordinary city, although there were many trades in it. Power was mostly used for crane and hoist work, 4½ and 7 H.P. being the sizes commonly used. There were also a number of larger motors (one of 60 H.P.) driving various classes of machinery, printing works, large ventilating fans and refrigerating machinery. In many cases these motors had been put in to replace gas engines, and the reports of the saving in cost had been most satisfactory.

Referring to the amount of 10 per cent. on the cost of the mains, this amount represented the actual revenue that should be received from a proposed consumer, in order to make it worth while incurring the cost of the necessary mains. If the amount per annum received from the consumer equalled 10 per cent. on the cost of the mains necessary to supply him, he considered that for any ordinary extensions it was policy to connect up.

He agreed with Mr. Dickinson that for very long extensions in outlying districts this amount should be carefully considered, and very probably increased. In fact, he thought that, in getting out the cost for each year, care should be taken to watch that figure and see that the general percentage of revenue to the cost of the mains was not getting too small. If it had a tendency to decrease, then the 10 per cent. should be increased in conformity with the general revenue.

As regards the cost of steam power, as compared with electric power, he thought that from 150 to 200 H.P. could be more economically supplied by the consumer himself than by purchasing current from a central station, that is to say, as long as such power was used continuously throughout the working hours of the day. An engine of 200 H.P. was as economical as a very much larger engine in a generating station, and there were no distributing charges to face in connection with the steam supply. There was a charge for labour in connection with the running of the steam plant, but from information he had received from mill-owners who had gone into the question, there was no doubt that they could produce steam as cheaply as electricity could be supplied at 1d. from a central station. Mr. Chattock.

With reference to the remarks on the load factor given, it included the lighting consumer as well as the private power consumers, but it did not include the power for tramways, although this came from the same station.

Most of the motors ranged from 1 to 10 H.P. There were 15, 20, and 60 H.P. motors in use, and there appeared to be an increasing demand for the larger size of motor, as they were slightly more economical.

He was very much interested in Mr. Wilkinson's remarks on oil-engines, viz., that 5 or 6 H.P. could be obtained for 1d. an hour. He took it that this was at full load, and that the cost of running an oil-engine at a reduced load would be considerably more. The great objection to oil-engines was the trouble in starting them and their objection to be considerably overloaded, which was a special point in favour of a motor supply. He also believed that Insurance Companies objected to the storing of a large quantity of oil, and there had been trouble in this respect. He thought that if oil-engines came into general use the price of oil would go up. Some time ago he was trying some oil fuel, and from the figures that were worked out he was satisfied that with oil at 2d. per gallon he could equal coal at about 18s. to 19s. per ton.

With reference to the question of continuous users of electricity using less current than those using it intermittently, this was quite possible. The continuous user very often ran his motor for many hours in order to get it at 1d., because if he stopped his motor he was charged at the rate of 2d. per unit. He thought it was best to base a sliding-scale charge on the number of units used per H.P. installed.

With regard to variable speed, he had not found any great demand for it. Possibly they had twenty or thirty motors, varying in size, in which this had been asked for and obtained, chiefly for running special machinery.

He did not agree that the cost of generation should include a portion of the rents, rates and taxes, and a charge on the mains, although that point should be watched. If the supply for motive-power purposes very much exceeded the supply for lighting, the cost of generation should be reckoned out to include more of the standing charges on the station and possibly on the mains, but as pointed out the motor overlap load was apparently very small at present, and in spite of the large

Mr. Chattock.

increase in the number of motors, it did not appear that this should be taken into account for some considerable time.

The figure that was quoted for the maintenance of the motors, viz., £1,723, looked rather high, but it included many spare parts, and also the supply of oil for running and general repairs, the cost of which was refunded by the hirer. It was really men's wages for inspecting and repairing the motors. The wages that were paid for inspection were higher than was the case in many towns, and it was looked upon rather in the form of an insurance. Every motor was inspected at least every two months, and most of them once a month. He thought that the benefit of it would be felt as time went on in the greater life of the motors, because if they were left to look after themselves they were liable to become very dirty. The consumer would not look after them, and he admitted that the commutators were a source of trouble if the motors were not looked after, consequently he did not think it a very heavy item. He thought it would pay the alternating-current consumer to look after his motors and to inspect them more frequently. Time would show if this amount could be reduced by giving up inspecting them so often, but at present he did not feel inclined to run the risk of doing so.

Mr. Emmott thought 15 per cent. on the capital cost of the apparatus was too great an amount to charge, and he recommended 12 per cent. He (the speaker), however, thought that the 15 per cent. charge should be made. The cost of motors during the last four years had dropped by about 30 per cent., and if the charge were 12 per cent. it certainly would not pay for the necessary inspection.

With reference to Sheffield beating Bradford he should be very pleased if they got ahead, but he thought that if the question of the H.P. installed per 1,000 of population were taken into consideration, Bradford would still be able to keep the lead, although the increase was not so great during the last two years. The increase in Sheffield was rather phenomenal on account of the supply being specially pushed just now. At the first everybody was coming on. Directly people began to see that the motors could be obtained cheaply and were doing well, they would all come on in a rush, and in a large town where there was a great amount of power undoubtedly this rush would be felt at first.

In Leeds, Mr. Dickinson said, they were getting 800 units per H.P. installed. In Bradford, however, there were not many motors running on a very heavy continuous load, the work being intermittent and chiefly used in crane and hoist work. The staple trade in Bradford was woollen, and all the mills had their own steam plant. There were not at the present time any motors in use for driving looms or wool-combing machinery. It was found that the people applied for motors for driving cranes and all small machinery where the load was intermittent, and there was no doubt that this accounted for the small number of units that were used per H.P. installed.

ORIGINAL COMMUNICATION.

MEAN HORIZONTAL AND MEAN SPHERICAL CANDLE-POWER.

By ALEXANDER RUSSELL, M.A., Member.

Introduction—Mean Horizontal Candle-power—How the Mean Horizontal Candle-power varies with the Area of the Candle-power Curve in Particular Cases—Mirror Effects of the Bulb—Rapid Methods of getting Mean Horizontal Candle-powers—Mean Spherical Candle-power—First Graphical Method—Mathematical Formula—Mean Hemispherical Candle-power—Second Graphical Method—Rapid Method of getting Mean Spherical and Mean Hemispherical Candle-powers—Conclusions.

The accurate rating of glow lamps, Nernst lamps, and arc lamps is a matter of considerable commercial importance, and so the following remarks on the mathematics of the question may not be out of place in the Journal. The physical side of the problem, namely, the quality of the light emitted and the best standards to use in the various cases, has not been touched upon.

English manufacturers as a rule do not guarantee that an 8-candle-power glow lamp gives a mean horizontal candle-power equal to eight candles, but merely that the mean horizontal candle-power is within 20 per cent. or so of eight. They do, however, guarantee a certain efficiency with particular classes of lamps, saying for example that their efficiency at the start is 3·5 watts per candle, and that after a thousand hours it is about 5 watts per candle. This method of rating lamps is to be commended, as it cheapens the cost of production and is quite fair to the consumer. By the candle-power of the lamp is meant the mean candle-power in a plane perpendicular to its axis, and this candle-power is also called its mean horizontal candle-power.

MEAN HORIZONTAL CANDLE-POWER.

If from a source S we draw lines equally in all directions in a plane and make their lengths equal to the candle-power in these directions, then the sum of all these lengths divided by their number gives the mean candle-power in that plane. When the axis of the lamp is vertical, the mean candle-power in the horizontal plane is called the mean horizontal candle-power. Now many inventors have tried to increase the mean candle-power in particular planes by means of reflectors and refractors, and some even think that they can increase the total quantity of light given out by the lamp by this means. As a proof they mention that they have increased the *area* of the candle-power curve in particular planes. This they have undoubtedly done in certain cases, but it does not follow that they have increased the mean candle-power in these planes. In fact, when we remember that by doubling the intensity of the source we can quadruple the area of the candle-power curve, the fallacy of their reasoning is apparent. The following mathematical examples illustrate how the area and the mean value of the radius of the candle-power curve can vary in certain cases.

If I be the mean value of radii $r_1, r_2, \ldots r_n$ drawn at equal angular intervals in a plane, then—

$$I = \frac{r_1 + r_2 + r_3 + \ldots + r_n}{n}$$
$$= \frac{r_1\,d\theta + r_2\,d\theta + \ldots + r_n\,d\theta}{n\,d\theta}$$
$$= \frac{\int_0^{2\pi} r\,d\theta}{2\pi}$$

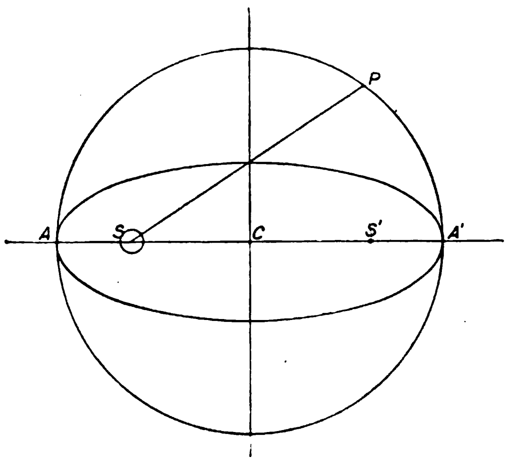


FIG. 1.—*S* is a source of light surrounded by an unevenly distributing globe which makes the candle-power curve in the plane of the paper the circle *A P A'*. Any radius vector like *S P* gives the candle-power in that direction.

$$\text{Mean candle-power} = \frac{\text{circumference of ellipse}}{2\pi}.$$

Now, suppose the candle-power curve to be a circle (Fig. 1), and let S, the source, be any point within it. We may suppose, for example, that the source is surrounded by an absorbing cylindrical globe of varying thickness so that the candle-power in the direction S P is represented by S P, and that the locus of P is a circle. We shall find an expression for the mean candle-power for different positions of S, supposing always that the candle-power curve remains the same circle.

If $SP = r$ (Fig. 1), $P\hat{S}A' = \theta$, $CS = a$, and $CA = R$, it is easy to show that—

$$r = a \cos\theta + \sqrt{R^2 - a^2 \sin^2\theta}.$$

Hence
$$I = \frac{\int_0^{2\pi} r\,d\theta}{2\pi}$$
$$= \frac{\int_0^{2\pi} \sqrt{R^2 - a^2\sin^2\theta}\,d\theta}{2\pi}$$
$$= \frac{\text{circumference of ellipse}}{2\pi}.$$

Where the ellipse (Fig. 1) has S for its focus and touches the circle at A and A'.

When S is at A,

$$I = \frac{2}{\pi} . CA$$
$$= 0{\cdot}637 . CA,$$

and when S is at C

$$I = CA.$$

Hence, although the candle-power curves have all the same area, yet the mean candle-power diminishes as S moves from C to A by about 36 per cent.

It is easy to see from the mathematical definition of mean candle-power that all curves of the family $r = a + b\,f(\theta)$, where $\int_o^{2\pi} f(\theta) = o$, have "$a$" for their mean candle-power.

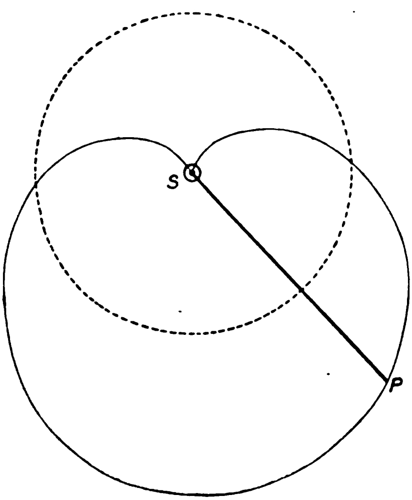


FIG. 2.—S is the source of light, and $S\,P$ gives the candle-power in the direction $S\,P$. Mean candle-power in the plane of the paper equals the radius of the dotted circle.

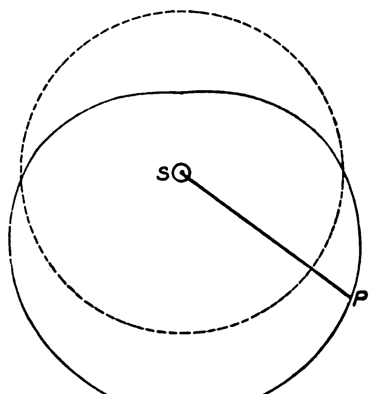


FIG. 3.—S is the source of light, and $S\,P$ gives the candle-power in the direction $S\,P$. Mean candle-power in the plane of the paper equals the radius of the dotted circle.

In the examples shown in Figs. 2 and 3, S is the source, and the mean candle-power of S would be the same whether its candle-power curves were given by the curves or circles shown. The equation to the curve in Fig. 2 is—

$$r = a\,(1 + \sin\theta),$$

and to the curve in Fig. 3—

$$r = a\,(1 + \tfrac{1}{2}\sin\theta).$$

In the first case the area of the curve is 100 per cent. greater than the area of the circle, and in Fig. 3 it is 25 per cent. greater.

Graphical Construction.

When we have a polar diagram of the candle-power given, an obvious graphical construction to find the mean candle-power is to construct a new polar curve (see Fig. 6) so that—

$$r_1 = r^{\frac{1}{2}},$$

then—

$$\text{Mean C.P. in given plane} = \frac{\int_0^{2\pi} r \, d\theta}{2\pi}$$

$$= \frac{\frac{1}{2}\int_0^{2\pi} r_1^2 \, d\theta}{\pi}$$

$$= \frac{\text{Area of new curve}}{\pi}.$$

If the candle-powers are given as in Figs. 4 and 5, then the mean horizontal candle-power is simply the mean height of the curve, *i.e.*, its area divided by its breadth.

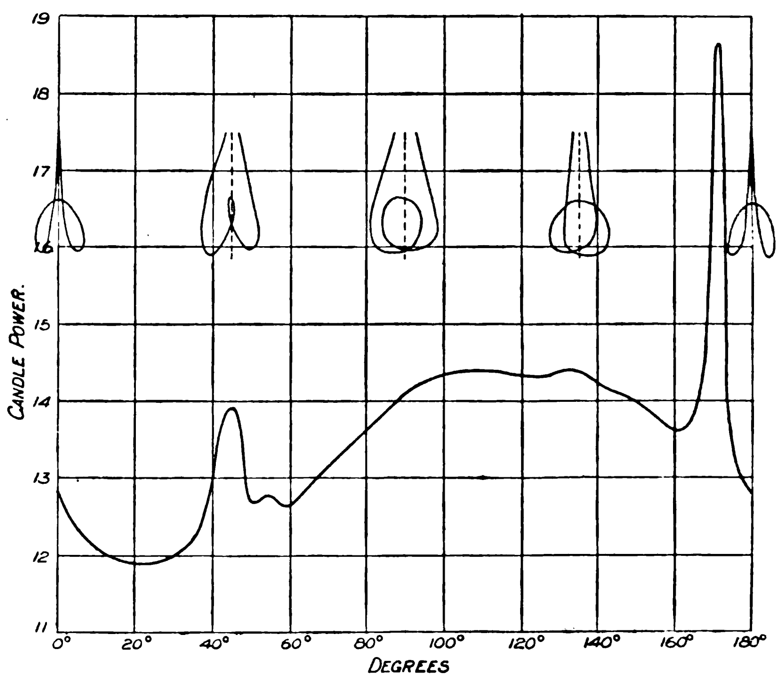


Fig. 4.—Mean horizontal candle-power curve round a clear bulb 16 candle-power glow lamp. Note the great rise of candle-power at 172 degrees due to the bulb acting like a concave mirror and concentrating the light on photometer disc. Distance of photometer head from lamp, about three feet.

Sufficient attention does not seem to be paid by practical men to the extraordinary way in which the horizontal candle-power of an ordinary glow lamp varies in different directions. In Figs. 4 and 5 are shown the results of the measurements of the candle-power of an ordinary glow lamp taken at intervals of every five degrees in the horizontal plane. The tests were made by two of my senior students,

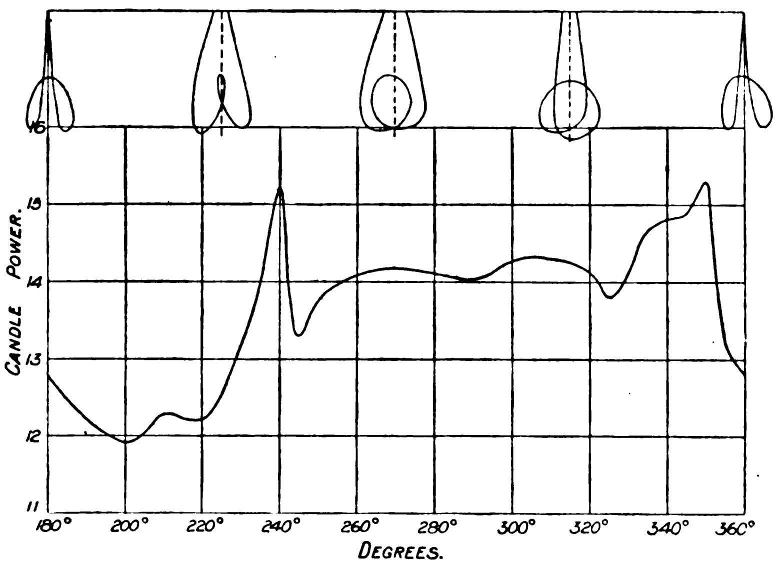


FIG 5.—Mean horizontal candle-power on the other side of the same lamp. Note the mirror effects at 240 degrees and at 350 degrees.

Messrs. Chubb and Morris, using a Lummer-Brodhun photometer, and they paid particular attention to the points where the candle-power altered rapidly. Their results may be taken as typical of how the horizontal candle-power of an ordinary glow lamp varies in different directions. The sudden variations are caused by the far side of the bulb acting like a concave mirror and concentrating the light on the photometer screen. In order to determine whether it acted like a lens or not a bulb was cut in two, but no trace of any lens effect could be found. The mirror effect was very pronounced, an image of a distant lamp being seen at a distance from the glass of about half the radius of curvature. On taking an ordinary lamp in your hand and looking into it with your back to a window two main images of the window will be seen, one erect and virtual formed by the front part of the bulb, the other inverted and real formed by the back part of the bulb. It is the back part of the bulb that causes the bright bands that can be seen on the shades of glow lamps. On putting your eye in line with a bright band coming from a glow lamp and moving it about, the image of the filament will be seen to behave in exactly the same manner as images do in concave mirrors. If a sheet of white paper be moved round it,

there will in general be positions in which bright bands of light are cast on the paper. Sometimes, especially in the case of ∩-shaped filaments, there will be dark bands. These dark bands are caused by one leg of the filament obscuring the light coming from the other leg. A ten per cent. dip from the mean is by no means unusual in this case.

When glow lamps are to be used as substandards of light it is necessary to test them first by finding their mean horizontal candle-power curve. If the candle-power is not sufficiently constant for a ten degree variation on either side of a given position, the lamp had better be rejected. Having found a suitable lamp and having marked distinctly and carefully the position in which it is to face the screen, it

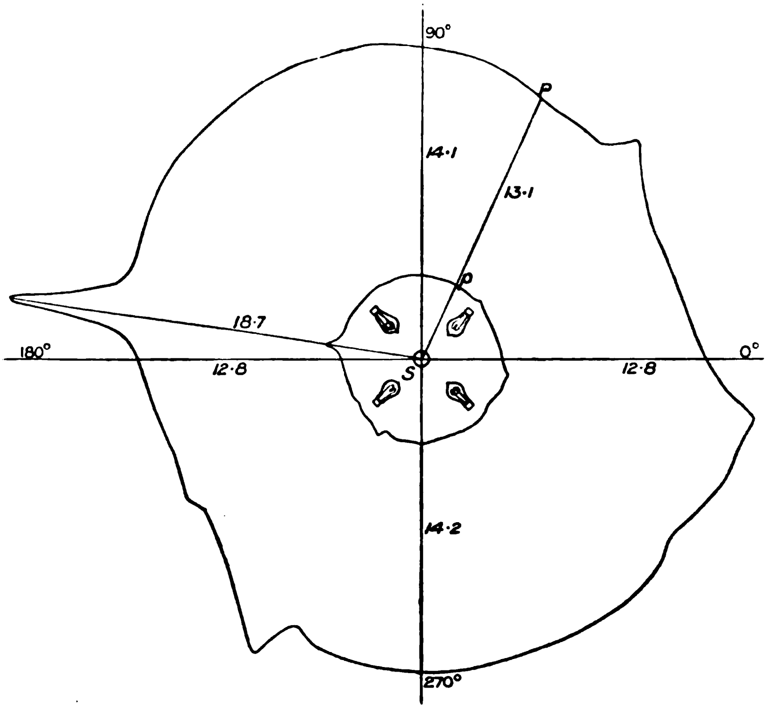


FIG. 6.—Polar horizontal candle-power curve of glow lamp. The radius vector $S\,P$ gives the candle-power in the direction $S\,P$. Also $S\,p = \sqrt{S\,P}$, and the area of the small curve divided by π gives the mean horizontal candle-power.

should then be run for a hundred hours, candle-power measurements being taken at frequent intervals to get an idea of the shape of the life curve. So far as constancy is concerned it is better to use low efficiency lamps as standards, and if care is taken that the pressure applied to them is never greater than the marked pressure and a record is kept of the time they are kept burning during tests, they will be found most satisfactory.

In Fig. 6, a polar curve of the candle-power of the glow lamp illustrated in Figs. 4 and 5 is shown. The mean horizontal candle-power was found by constructing a new curve, the lengths of whose radii are the square roots of the corresponding radii of the candle-power curve. The area of this curve divided by π gives 13·5 as the mean hemispherical candle-power of the lamp, a result which was verified by taking the mean height of the curves shown in Figs. 4 and 5.

As a rule, not much attention is paid to the mean vertical candle-power of ordinary glow lamps. The curve shown in Fig. 7 may be taken as typical.

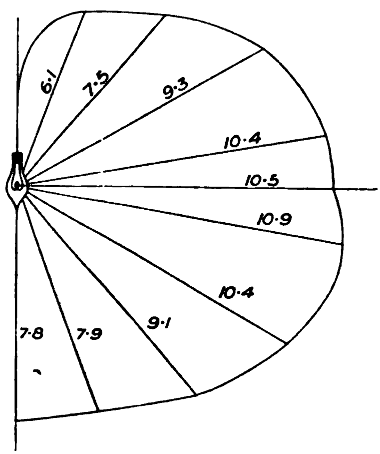


FIG. 7.—Vertical candle-power curve of ordinary glow lamp.

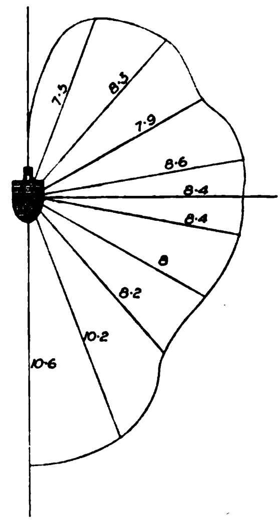


FIG. 8.—Vertical candle-power curve when a spiral glass rod twisted into the shape of a cup is placed round a glow lamp.

In Fig. 8 is shown the vertical candle-power curve of this lamp when a spiral rod twisted into the shape of a cup is placed round it. The shape of the candle-power curve is altered, but the change in the mean vertical candle-power is very slight.

RAPID METHODS OF GETTING THE MEAN HORIZONTAL CANDLE-POWER.

When the lamp is rotated, the centrifugal force alters the position of the filaments and generally alters the mean hemispherical candle-power. There is also a risk of the filaments breaking. Still, for rough measurements, the method is a good one.

Another method is to use four equal pieces of looking-glass cut from the same strip. Two of these pieces inclined to one another at 120

degrees are placed behind the standard lamp, and an exactly similar arrangement is placed behind the lamp being tested. If then the candle-power of the lamp being tested is approximately the same as that of the standard and the mean horizontal candle-power of the standard is accurately known, we get by one reading an approximation to the mean of three, and so time is saved. Great accuracy, however, is not obtainable by this method if only one reading is taken, as variations of five per cent. can be obtained by rotating the lamp into different positions, these variations being mainly caused by the positions of the bright bands.

Experiments were made with diffusive reflectors, but in no case could we make sure of obtaining a five per cent. accuracy by one reading. Better results would probably be obtained by using uniform ground-glass cylindrical chimneys to put round the lamps when being tested.

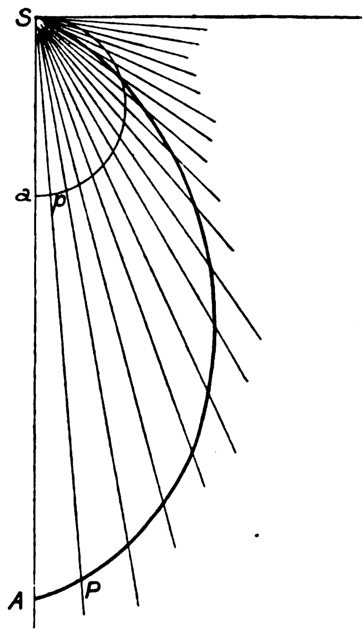


FIG. 9.—The revolution of $S P A$ about $S A$ produces the candle-power surface. Make a new curve $S p a$ so that $S p = \sqrt[3]{S P}$. Then the mean spherical candle-power $= \frac{3 V}{4 \pi}$, where V is the volume generated by the revolution of $S p a$ round $S a$. Mean spherical candle-power $= 0{\cdot}125\ S A$.

MEAN SPHERICAL CANDLE-POWER.

If we draw from the source, equally in all directions, lines whose lengths are proportional to the candle-power in these directions, then the mean value of the lengths of all these lines is the mean spherical candle-power. If $r_1, r_2 \ldots r_n$ be the intensity of the light in the various directions, then—

$$\text{M.S.C.P.} = \frac{r_1 + r_2 + \ldots + r_n}{n}$$

$$= \frac{\Sigma\, r\, d\omega}{4 \pi},$$

where $d\omega$ stands for a very small solid angle.

Hence, if we construct a new surface so that—

$$r_1 = r^{\frac{1}{3}},$$

then—

$$\text{M.S.C.P.} = \frac{\Sigma\, r_1^3\, d\omega}{4\,\pi}$$
$$= 3\,\frac{\Sigma\, d\,\text{V}}{4\,\pi}$$
$$= \frac{3\,\text{V}}{4\,\pi},$$

where V is the volume of this new surface.

It will be seen that an exact solution of the general problem is complicated. When, however, as is generally permissible in practice, we may suppose that the extremities of all the lines representing the candle-powers lie on a surface of revolution, various simple graphical methods may be given to find the main spherical candle-power.

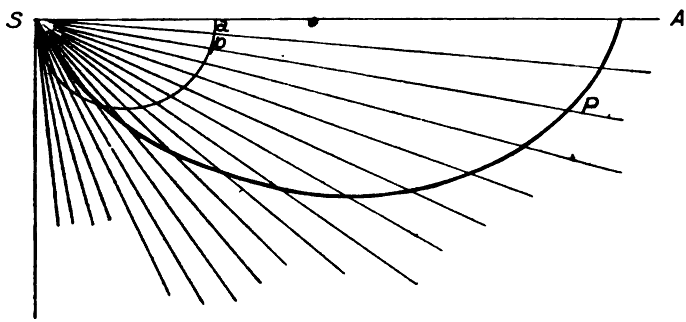


FIG. 10.—*S P A* is the polar curve of candle-powers in directions below the horizontal in a vertical plane. If the top polar curve be similar, then the mean spherical candle-power = 0·589 *S A*.

First Graphical Method.

We first find by experiment the polar curve S P A (Fig. 9), whose revolution produces the candle-power surface. We then construct a new curve S*p a* so that—

$$\text{S}p = \text{SP}^{\frac{1}{3}}\,.$$

It follows that the—

$$\text{M.S.C.P.} = \frac{\text{S P}\, d\omega + \ldots}{4\,\pi}$$
$$= \frac{\text{S}p^3\, d\omega + \ldots}{4\,\pi}$$
$$= \frac{3\,\text{V}}{4\,\pi}$$
$$= \frac{3}{4\,\pi} \times 2\,\pi\, h \times \text{Area S}p\,a,$$

where h is the perpendicular distance of the centre of gravity of the area S*p a* from S A.

For example, in Fig. 9 the curve $S p a$ is a circle. Hence in this case the—

$$\text{M.S.C.P.} = \frac{3}{4\pi} \times 2\pi\left(\frac{2\,S a}{3\pi}\right) \times \frac{\pi}{2}\left(\frac{S a}{2}\right)^2$$
$$= \frac{1}{8}\left(S a\right)^3$$
$$= \frac{1}{8} \, . \, S A.$$

Similarly in Fig. 10, where $S p a$ is a circle (only half the curve is drawn)—

$$\text{M.S.C.P.} = \frac{3}{4\pi} \times 2\pi R \times \pi R^2$$
$$= \frac{3\pi}{2} R^3$$
$$= \frac{3\pi}{16} S A.$$
$$= 0{\cdot}5890 \; S A.$$

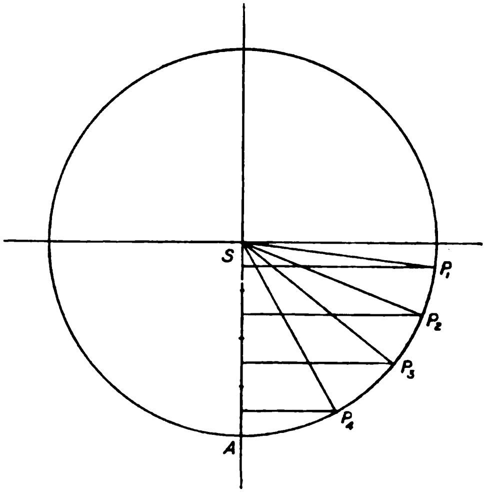


FIG. 11.—Construction for finding the directions in which to measure the candle-powers whose mean value will give us the mean spherical candle-power. $S A$, the lower radius of a circle, is divided into any number of equal parts, and through the middle points of these equal parts lines are drawn perpendicular to $S A$. $S P_1$, $S P_2$, etc., are the required directions.

ANOTHER EXPRESSION FOR THE M.S.C.P.

With the source S as centre, describe a sphere (Fig. 11) of radius R. Divide the vertical diameter of this sphere into any number of equal parts, and through the points of section draw planes perpendicular to

this diameter, then these planes will intersect zones of equal area on this sphere. This follows from elementary mensuration, since the area of the zone of a sphere is $2\pi R h$, where h is the perpendicular distance between its two bounding planes. Now, if we take the mean value of the candle-powers in the directions of all the radii drawn to one of these zones and do the same for all the others, the mean of all these results will give us the mean spherical candle-power.

For the case of a surface of revolution, if $R = n h$—

$$\text{M.S.C.P.} = \frac{r_1 + r_2 + \ldots + r_{2n}}{2n}$$

$$= \frac{r_1 h + r_2 h + \ldots}{2R}$$

$$= \frac{\Sigma r h}{2R}.$$

Now $\quad h = R\, d\theta \cos\theta$,

$$\therefore \quad \text{M.S.C.P.} = \tfrac{1}{2}\int_{-\frac{\pi}{2}}^{+\frac{\pi}{2}} r \cos\theta \, d\theta$$

$$= \tfrac{1}{2}\int_{-\frac{\pi}{2}}^{+\frac{\pi}{2}} x \, d\theta,$$

which is a simple formula.

For example, if the polar curve of candle-power be the semicircle of $S p a$ in Fig 9, and a similar semicircle above the horizontal, then

$$\text{the M.S.C.P.} = 0{\cdot}5 \;.\; S a.$$

Similarly, if it were the circle half of which is shown in Fig. 10,

$$\text{the M.S.C.P.} = \tfrac{1}{2}\int_{-\frac{\pi}{2}}^{+\frac{\pi}{2}} 2R \;.\; \cos^2\theta \, d\theta$$

$$= \frac{\pi}{2} R$$

$$= 0{\cdot}7854 \;.\; S a.$$

The equations to the curves shown in Figs. 2 and 3 are of the form—

$$r = a + b \sin\theta.$$

Hence the M.S.C.P. of the surfaces of revolution of which they are sections—

$$= \tfrac{1}{2}\int_{-\frac{\pi}{2}}^{+\frac{\pi}{2}} (a + b\sin\theta)\cos\theta \, d\theta$$

$$= a$$

The curves shown in Fig. 12 are parts of circles; in this case—

$$\text{M.S.C.P.} = 0{\cdot}555 \,.\, \text{O A}.$$

In Fig. 2 the ratio of the two hemispherical candle-powers is as one is to three.

Mean Hemispherical C.P.

In this case we only take the mean value of the candle-power over a hemisphere. The formula is—

$$\text{H.C.P.} = \int_{0}^{+\frac{\pi}{2}} x \, d\theta,$$

For example, in Figs. 2 and 3—

$$\text{Upper H.C.P.} = a - \tfrac{1}{2}\, b.$$
$$\text{Lower H.C.P.} = a + \tfrac{1}{2}\, b.$$

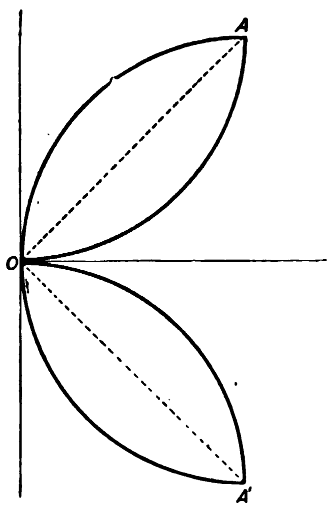


Fig. 12.—The revolution of the polar curves shown, which are parts of circles, gives us the candle-power surface. Mean spherical candle-power = 0·555 OA.

Second Graphical Method.

Having given the polar curve of candle-power A P B C (Fig. 13) construct a new curve so that—

$$o\,p = \sqrt{o\,\text{N}},$$

then the area of this new curve gives the M.S.C.P. For—

$$\text{Area of Curve} = \tfrac{1}{2}\int_{-\frac{\pi}{2}}^{+\frac{\pi}{2}} o\,p^2\,d\theta$$

$$= \tfrac{1}{2}\int_{-\frac{\pi}{2}}^{+\frac{\pi}{2}} x\,d\theta\;. = \text{M.S.C.P.}$$

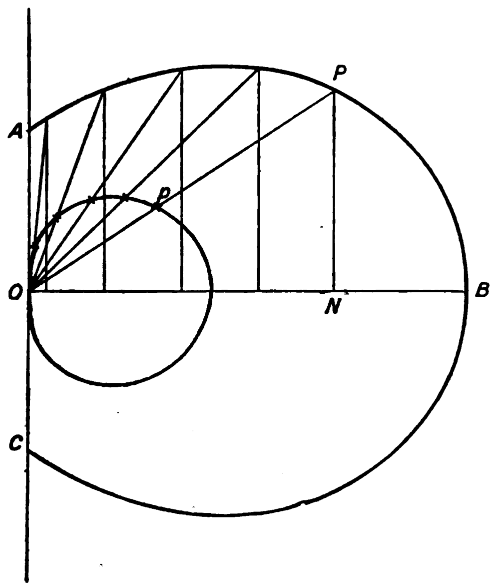


FIG. 13.—O is the source of light and $A\ P\ B\ C$ is the polar curve of candle-power. Make $O\,p = \sqrt{O\,N}$ and construct the curve locus of p. The mean spherical candle-power = the area of the small curve.

RAPID METHODS OF FINDING M.S.C.P.'s.

The following approximate methods will be found of practical value. The theory will be best understood by considering a particular case. Divide a sphere described round the source as centre into eight equal zones (Fig. 11). Through the centres of the equal parts into which the radius is divided draw perpendiculars meeting the surface in P_1, P_2, P_3, and P_4 respectively, and suppose that corresponding lines are drawn for the upper hemisphere. Then we may assume that the candle-powers in the directions $S\,P_1$, $S\,P_2$, etc., are all equally important.

Hence $$\text{M.S.C.P.} = \frac{r_1 + r_2 + \ldots + r_8}{8}.$$

where r_1, r_2 . . . are the intensities of the light in the directions $S P_1$, $S P_2$. . . . The lower hemispherical candle-power would be given by the approximate formula—

$$\text{Lower H.C.P.} = \frac{r_1 + r_2 + r_3 + r_4}{4}.$$

If we find the angles of depression, $S P_1$, $S P_2$ . . . once for all, then we can take these as standard directions. The mean spherical candle-power can be got directly by this method without any graphical construction.

If the lower radius be divided into $2\,n$ portions, then the angles are given by the equations—

$$\text{Cos } \theta_1 = 1 - \frac{1}{2\,n}.$$

$$\text{Cos } \theta_2 = 1 - \frac{3}{2\,n}.$$

$$\text{Cos } \theta_n = 1 - \frac{2\,n - 1}{2\,n} = \frac{1}{2\,n}.$$

If radii be drawn making angles $\pm\,\theta_m$ with the horizontal, and if I_m and I'_m be the intensities of the light in these directions, then—

$$\text{M.S.C.P.} = \frac{I_1 + I_2 + \ldots + I_1' + I_2' + \ldots}{2\,n}.$$

$$\text{Upper H.C.P.} = \frac{I_1 + I_2 + \ldots}{n}.$$

$$\text{Lower H.C.P.} = \frac{I_1' + I_2' + \ldots}{n}.$$

The following are the values of θ_1, θ_2, etc., when 2, 4, 6, 8, 10, or 20 measurements of candle-power are to be made :—

Number of Measurements.	Angles of Depression or Elevation from Horizontal in Degrees.
2	30
4	14·5, 48·6
6	9·6, 30, 56·4
8	7·2, 22, 38·7, 61
10	5·7, 17·5, 30, 44·4, 64·2
20	2·9, 8·6, 14·5, 20·5, 26·7, 33·4, 40·5, 48·6, 58·2, 71·8

Approximations to the mean spherical candle-power of any required accuracy can thus be obtained by measuring the candle-powers in the directions of the angles given above and taking the arithmetical mean of the results.

In order to illustrate the accuracy of these approximations the following numerical examples have been worked out :—

In Fig. 10 the lower hemispherical candle-power of the polar curve S A P comes out as follows :—

Number of Measurements.	Lower H.C.P.
1	0·6495
2	0·5979
3	0·5924
4	0·5904
5	0·5901
10	0·5893
Infinite	0·5890

The first approximation is simply got by measuring the candle-power at 30 degrees, the next by taking the mean of the values at 14·5 and at 48·6 degrees respectively, and so on.

In this case the mean of the candle-powers in directions 9·6, 30 and 56·4 would have been sufficiently accurate.

The following are the approximations to the lower hemispherical candle-power of the polar curve S P A in Fig. 9.

Number of Measurements.	Lower H.C.P.
1	0·1250
2	0·2188
3	0·2359
4	0·2422
5	0·2450
10	0·2500
Infinite	0·2500

Many other examples have been worked out, and it has been found that the mean of five observations at angles of 5·7, 17·5, 30, 44·4, and 64·2 are quite sufficient for practical requirements.

Even, however, when theoretically-accurate methods like Rousseau's or the graphical methods we have described are employed, it is always best to measure the candle-powers in the directions given above for the tenth approximation and not at ten equal angular intervals, because in this latter case undue importance is attached to measurements at 60, 70 and 80 degrees. As a rule, an error in the measurement when the angle of depression is ten degrees is much more serious than when the angle of depression is eighty degrees.

The points to which attention is called in this paper are the following :—

1. The bulbs of glow lamps act like concave mirrors producing bands of light in particular directions. Dark bands are produced when a vertical portion of the filament is parallel to another portion of it. These effects produce very rapid azimuthal variations of the light.

2. In determining the mean hemispherical candle-power of glow lamps, when no reflectors or diffusers are used, a large number of observations must be made. This number may be reduced by using suitable reflectors or diffusers. If we rotate the lamp, besides the risk of the filament breaking, the centrifugal force must alter its shape, thus altering the total distribution of the light in space.

3. When glow lamps are used as standards it is of vital importance to study the horizontal candle-power curve before choosing and marking the direction in which they are to face the photometer screen. Neglect of this precaution even with ∩-filament lamps leads to large errors. As a rule the plane of the filament is perpendicular to the axis of the bench. The mean horizontal candle-power curves got by comparing a lamp with two standards of different powers may show distinct variations due to the relative mirror effects of the bulb being different at varying distances of the photometer screen from the lamp.

4. Several simple formulæ and graphical constructions are given for determining the mean spherical and the mean hemispherical candle-power of sources of light.

5. The simplest practical method of determining the mean lower hemispherical candle-power of an arc lamp is to measure its candle-power in directions making angles of 5·7, 17·5, 30, 44·4, and 64·2 degrees with the horizontal, and taking the mean of the results. The easiest way of drawing these angles is by the graphical construction indicated in Fig. 11. If greater accuracy is required, the same thing can be done in several vertical planes passing through the axis of the lamp and the mean of the results taken.

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GLASGOW LOCAL SECTION.

A STUDY OF THE PHENOMENON OF RESONANCE IN ELECTRIC CIRCUITS BY THE AID OF OSCILLOGRAMS.*

By M. B. FIELD, Member.

(*Paper read at Meeting of Section, February* 10*th*, 1903.)

Three factors are generally essential to enable an intelligent investigator to satisfactorily complete any experimental research, viz., time, inclination, and apparatus.

During the last two years I have been in the enviable position of having at my disposal plant and apparatus, from which by careful study many important and, I believe, little understood phenomena might be investigated. The inclination on my part to make the best use of the opportunity afforded certainly was not wanting; but the small quantum of available spare time has hindered me from bringing to a satisfactory termination several investigations on which I have been at work.

As in future I shall not have in the same way facilities for continuing this work, I venture to lay before you in all their incompleteness certain results I have arrived at, and to ask you to consider these as mere suggestions, which may act as an incentive to some other fortunate investigator, who may have the time, apparatus, and inclination necessary for completing the work.

My subject is more particularly some aspects of electrical resonance which occurred to me on observing the shape of the E.M.F. wave of the 2,500 kw. generators of the Glasgow Corporation Tramways Department. These curves were depicted on the tracing desk of one of those beautiful instruments invented by Mr. Duddell, viz., the high frequency pattern of oscillograph.

* This Paper was also read in abstract in London on March 12th, 1903, and was discussed jointly with Messrs. Constable and Fawsett's Paper, "Distribution Losses in Electric Supply Systems," at Meetings of March 12th, 26th and April 23rd, 1903. See pages 734, 740, and 762.

At first I contented myself with merely tracing on paper the curves thrown upon the desk of the apparatus. When, however, I wished to obtain curves which were to play an important part in some of the official tests of the Glasgow plant, I considered this method too inaccurate, and had constructed several special dark slides in which a bromide paper or sensitive film could be stretched round a glass shaped to the proper curvature, and by means of which records could be taken photographically and the human element obviated. These dark slides were cheap to construct, and very useful, and were used almost entirely in the experiments I am about to describe.

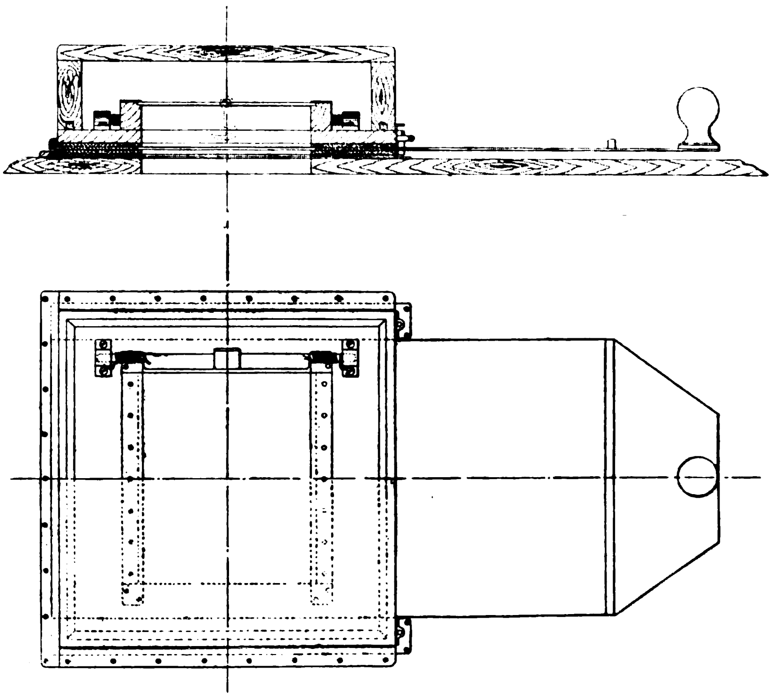


FIG. I.

Fig. 1 is a drawing of the dark slide, which is self-explanatory. In using these, of course, all stray light must be screened off to obtain the best results; and in this connection I found it useful to employ a screen (S, Fig. 2) to cut off all light from the bright lacquered parts of the oscillograph. Many of these parts are best painted with a dead black paint, while it is of the highest importance to entirely cover the bright steel face containing the saw-cuts in which the vibrating strips are set. I found it advantageous to make several slight modifications of this kind in the apparatus as supplied by the makers in order to obtain the best results with the dark slides above mentioned.

It may be of interest to call attention here to a few of the idiosyncrasies of the type of oscillograph employed.

In the first place, I experienced considerable difficulty due to the shifting of the zero of the vibrating mirror. The apparatus contains a fixed mirror which gives a fixed zero line, and it is necessary to adjust each of the vibrating mirrors so that the base line (they project when no current is flowing through them) coincides with the fixed zero line. After the strips have been in circuit for a short while, however, I found frequently that the zero line had shifted, which produced the apparent result of larger positive half-waves than negative half-waves, or *vice versa*. Again, there is a tendency for the cam which vibrates the mirror to wear, and the greatest wear occurs towards the end of the motion, since here the pressure on the cam is greatest. This wear affects the horizontal, but not the vertical, displacement, the latter still being directly proportional to the current flowing. In some cases, therefore, where the positive and negative half-waves were obviously

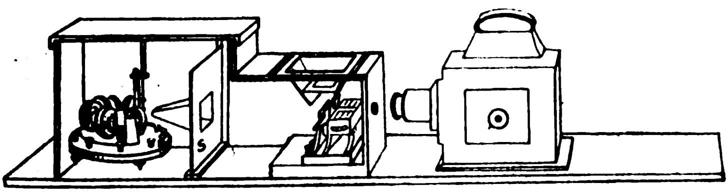


FIG. 2.

identical, I found it advantageous to apply a correction in the following way:—Two lines were drawn parallel to the fixed zero line touching the highest point of the positive and negative waves; the distance between these lines was halved and a corrected zero line drawn in; the positive half-wave was then reversed and substituted for the negative half, thus almost entirely eliminating the above-mentioned effects. This, of course, would not be permissible where the positive and negative half-waves were of different shape. I may say that all the curves here reproduced have been *uncorrected* in this manner.

Another difficulty I experienced was due to the violent hunting of the oscillograph motor when running under abnormal conditions. Under these circumstances two distinct waves would be apparent on the photograph, representing the limiting positions of the actual wave which the projection of on the screen was shifting backwards and forwards with great rapidity, instead of being stationary, as it should have been.

Sometimes this hunting was caused by the variation of load on the oscillograph motor (the tension of the spring controlling the mirror varying from zero to a maximum in each revolution).

Curve I. represents the E.M.F. curve of the system under normal load conditions, with one 2,500 kw. generator only running on the load, and supplying 245 amperes per phase. The generators are 6,500 volt, 3-phase, 75 r.p.m. machines, with stationary armatures having two

slots per pole per phase, and 40 poles. Curve I, as also practically all oscillograms reproduced in this paper, was taken from the low-tension side of a bank of transformers in one of the sub-stations; there were thus a bank of transformers and a high-tension 3-core cable intervening between the oscillograph and the generator terminals.

I fully recognise that it would have been more to the point had some of my measurements been made in the high-tension circuit itself. I even constructed a resistance to insert in one of the legs of the

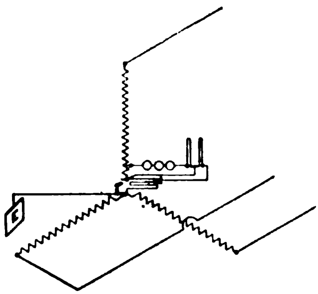
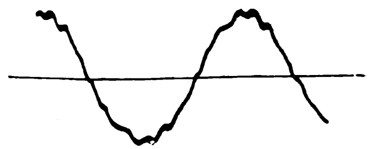


FIG. 3.



CURVE I.—E.M.F. Wave of Generator on normal traction load, 245 amps. per phase.

armature winding, and took a tapping off one of the coils near the neutral point, as shown in Fig. 3. It was my intention to connect the neutral point of the generator to earth during these experiments in order to secure safety, it being normally insulated from earth. I had not, however, the same facilities in the power-house as in the sub-station, and unfortunately did not conduct any experiments in the former place.

The arrangement generally adopted was that shown in Fig. 4—

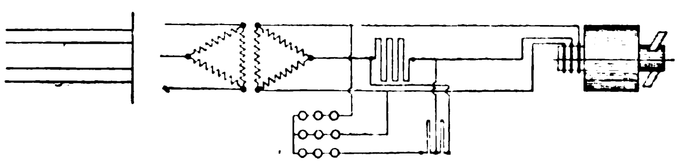


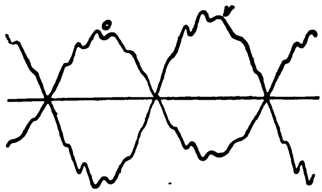
FIG. 4.

The transformer groups consist each of three 200 kw. single-phase transformers connected △ — system, and loaded on rotary converters. The high-tension cables are as follows:—

To Sub-station	A	4 — 3-core	·15 in.	Length = 4849 yards	each.
„	B	4 — 3-core	·1 in.	„ = 4,775	„
„	C	4 — 3-core	·1 in.	„ = 5,899	„
„	D	4 — 3-core	·1 in.	„ = 2,286	„
„	E	4 — 3-core	·15 in.	„ = 5,605	„

An examination of Curve I. will show at a glance that there are harmonics of a high order present in the wave form. Curve II.

represents the voltage and current wave forms taken from the low-tension side of one of the 200 kw. transformers partially loaded on a water resistance. It will be noticed that for clearness the current wave has been reversed, that there is apparently no phase displacement, and that the harmonics of the current wave follow closely those of the E.M.F.



CURVE II.—E.M.F. and Current Waves from Transformer on water load.

Assuming we can represent the E.M.F. wave by the expression

$$E = \Sigma E_i \sin(2\pi i n t + c_i) \quad . \quad . \quad (1)$$

n being the natural frequency of the system, *i.e.*, 25 cycles per second, and the summation being extended to all terms obtained by giving i successive integral values from 1 upwards, then the true voltmeter reading of E, or the effective volts, will be—

$$\sqrt{\frac{\Sigma E_i^2}{2}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

and provided the water load acts as a true non-inductive resistance, and one without capacity, *i.e.* provided no periodic storage and discharge of energy occurs in the water resistance, the current will be expressed by—

$$\frac{1}{R} \Sigma E_i \sin(2\pi i n t + c_i) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

and the true ammeter reading by $\frac{1}{R}\sqrt{\frac{\Sigma E_i^2}{2}}$ . . . . (4)

The products of the ammeter and voltmeter readings will then be—

$$\frac{1}{2R} \Sigma (E_i^2) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

The instantaneous value of the watts, obtained by multiplying the instantaneous values of voltage and current strength, is—

$$\frac{1}{R}\left\{ \Sigma E_i \sin(2\pi i n t + c_i) \right\}^2 \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

the average value of this, or the true wattmeter reading, is, of course, again represented by the expression (5); in other words, if the load be a pure ohmic resistance, the product of true volts and true amperes represents true watts, no matter how irregular the wave-shapes may be.

Now the value of (2) may be obtained from the oscillogram of the voltage, by taking the square root of the average value of the squares of a number of equi-distant ordinates.

Similarly the value of (4) may be determined from the current oscillogram.

Multiplying these together we obtain the value of (5).

The average value of (6) may be determined by first multiplying the ordinates taken from the current and voltage oscillograms, and then taking the mean.

To test the water load, as also the oscillograph, I obtained arithmetically the values of (2), (4), (5), and the average value of (6), as described from the oscillograms, and in every case obtained agreement within 1 per cent.

It is clear that, had the load possessed any properties of the nature of self-induction or capacity, or if such factors existed in the oscillograph itself, such agreement would not have been obtained.

It was natural to inquire what effect the harmonic or ripple in the E.M.F. wave would have on the voltage at the rotary D.C. brushes. To show this, I drove the oscillograph motor from the rotary slip-rings, connecting one strip across the D.C. brushes, and one strip between one slip-ring and one D.C. brush (see Fig. 5).

The result was Curve III. A distinct ripple was observable in the D.C. voltage under normal load conditions, and by comparing it with the wave length of the undulating wave we find the number of ripples

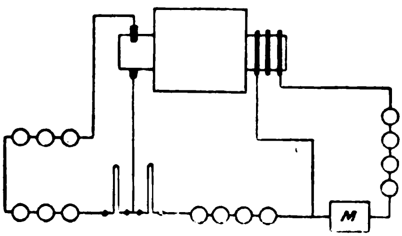
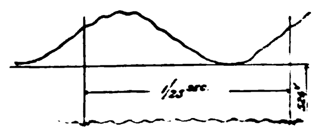


FIG. 5.



CURVE III.—D.C. Voltage of Rotary on no Load and E.M.F. between one D.C. brush and slip-ring.

in the D.C. voltage per period is 12; in other words, there is an alternating E.M.F. of 300 cycles superimposed upon the D.C. voltage of 500 volts.

It is clear that the E.M.F. between one slip-ring and one commutator brush will be an undulating E.M.F. either wholly positive or wholly negative. If the negative D.C. brush is at zero potential, and provided the rotary is on load, and the brushes are in the neutral position, clearly every other point in the armature, if not at zero potential, must be between zero and the potential of the + D.C. brush. Now, each slip-ring becomes connected directly to the + and — brush alternately once per cycle, hence shape of wave.

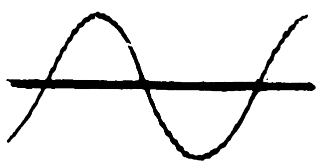
Until I saw this experiment I had half doubts that the ripples in the A.C. voltage were introduced by the oscillograph itself. When, however, I ran a rotary as a double current generator, self-excited, driving it by means of its starting motor, the D.C. voltage shown by the oscillograph was a perfectly straight horizontal line, and the A.C. wave was entirely devoid of ripples except of a very much higher frequency and small amplitude.* (See Curve IV.)

* From Curve IV. it appears as though there were 35 or 37 ripples per period. It may be pointed out that the armatures of these rotaries are six-polar, and have 108 slots, this apparently corresponding to the number of ripples in the oscillogram.

The process of parallelling could be watched on the oscillograph screen, and a most fascinating sight it is to watch the D.C. voltage spring from the straight line to a wave with ripples along the whole length, and then to see the main wave instantaneously straighten out, the ripples only remaining as the rotary is pulled into the correct phase. The instantaneous formation of the ripples on the A.C. curve can in like manner be watched.

It was easy, however, to demonstrate the existence of the D.C. ripples independently of the oscillograph, and for this purpose I drove one rotary by an independent motor as a D.C. generator, and a second rotary parallel with the power-station in the usual way. The two + brushes were connected together, and the negative brushes through a hot-wire voltmeter in parallel with a Weston. The excitation was adjusted till the latter voltmeter read zero; the hot-wire instrument on the other hand indicated 12 volts. The latter instrument was, of course, merely measuring the square root of the mean square of the ripple.

This corresponds to a total fluctuation from crest to hollow of 34 volts, or, say, *under normal running conditions*, 6·8. I have tried to filter out the alternating component of the D.C. voltage, and transform it up, by passing it round one winding of a static transformer, neutralising the magnetic saturation created by the D.C. component by a current from a battery, but I have not succeeded in doing it.



CURVE IV.—E.M.F. Curve of Rotary as A.C. Generator.

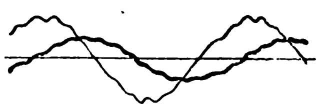
If I could have borrowed a 500-volt accumulator battery in order to oppose it to the D.C. voltage of the rotary, I think I could have obtained a considerable 300-cycle current through the battery. As I shall show afterwards, I am able to accentuate these D.C. ripples considerably under special circumstances.

I further observed the current flowing into the D.C. feeder circuits of the tramway system, but could find practically no trace of a ripple at all. The loss in outside circuits due to the ripple was therefore negligible.

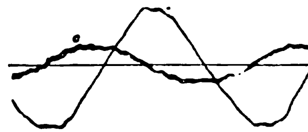
If we took the square root of méan square of the voltage ripple as 3 per cent. of 500 volts, and the current ripple in proportion, viz., 3 per cent., and if we assumed that the whole of the A.C. component was wasted in heat, it would represent merely 9 units in 10,000. I am therefore justified in saying that under normal conditions the loss due to the D.C. ripple does not amount to 1 per mil.

There is no doubt that the source of these ripples lies in the teeth of the generators, there being 12 teeth per period and 12 ripples per cycle superimposed on the D.C. voltage. The ripples exist in the high-tension voltage, pass through the transformers, through the rotaries to the D.C. side, and if other rotaries be run as motors from the D.C. 'bus-bar, the ripples reappear at the A.C. slip-rings. It seems impossible to get rid of them by filtering them out. We have already

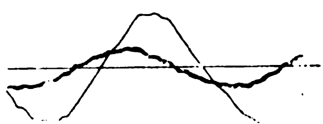
disposed of the suggestion that they originate in the rotaries themselves. I think no one will venture to assert that the transformers manufacture them. One way to decide that point would be to connect the oscillograph direct in the high-tension circuit; although I have not done this, I have another proof (although to my mind no proof is necessary), and that is, when one generator only is running in the power-house the ripples are always present, though somewhat wavering at times—when two generators are running in parallel the ripples often alternately appear and disappear with a regular periodicity lasting several seconds. This is evidently due to the swinging of one



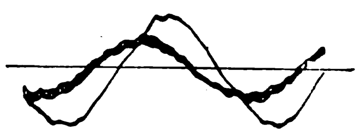
CURVE V.—Current and E.M.F. of Rotary on no load, under-excited. Lagging current into rotary = 650 amps.



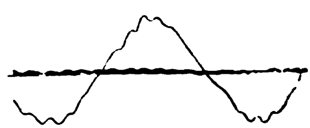
CURVE VI.—Same as V., but over-excited. Leading current into rotary = 600 amps.



CURVE VII.—Current and E.M.F. of Rotary on normal traction load, in parallel with two others.



CURVE VIII.—Current and E.M.F. of Rotary on normal traction load, in parallel with one other.



CURVE IX.—E.M.F. and Current of Rotary on no load, excitation adjusted to give minimum armature current.

generator relatively to the other; when exactly in phase the ripples appear, when displaced by half the wave length of the ripple they practically disappear. The same thing happens with the ripples in the A.C. voltage. I have seen an almost rounded A.C. voltage curve suddenly jump into peaks as one generator was switched out of parallel.

Granting, then, that the generator E.M.F. wave possesses high harmonics, and the back E.M.F. of the rotaries is a smooth wave (as indeed one would expect from such a type of armature, and as is shown to be the case in Curve IV.), it is evident that the rotary can supply no back E.M.F. to equilibriate the ripples of the applied E.M.F. What must happen in such a case is that when the opposing E.M.F.'s do not balance owing to a ripple in the one and not in the other, a

wattless—which I afterwards call a self-induction—current must rush in or out of the rotary, which will absorb or equilibriate the difference of voltage. Curves V. to IX. show this clearly. In the latter case the rotary was running unloaded under condition of minimum armature current. It will be seen that the amplitude of the ripples of the current waves seems larger than that of the main wave itself, the latter being scarcely distinguishable.

It is interesting to note that the current wave is rippled more uniformly than the voltage wave.

The main drift of the first portion of this paper is to discuss the conditions under which resonance may occur with one of the higher harmonics of the E.M.F. wave introduced by the particular form of toothed armature in use at the power-station. Let us first examine the construction of the armature. Fig. 6 is reproduced from a scale drawing of the armature slots, and field magnet pole-shoes. From an examination of this figure it will be obvious that the magnetic flux must

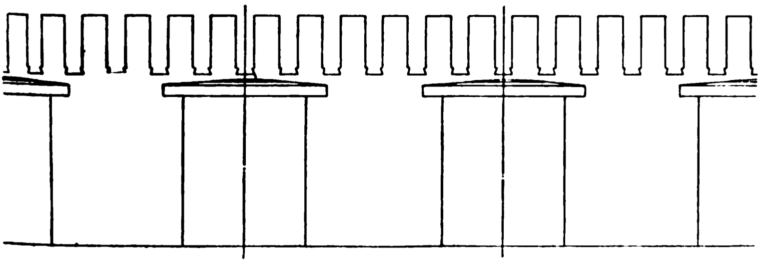


FIG. 6.

be constantly shifting backwards and forwards along the pole-face as tooth by tooth of the armature is passed. It does not necessarily mean that the total flux through the field system fluctuates, but that this flux emerges from the pole-face in "tufts" opposite the armature teeth, and that these tufts of magnetism are dragged backwards, and spring forwards along the pole-face according as the magnetic reluctance is charged at different parts of the same by the change of position relative to the armature teeth. The poles are champfered off so as to avoid as far as possible change of total flux through the field system. I do not think this goes on to any marked extent; it would be possible to detect such periodic changes by looking for fluctuations of exciting current. This could be done by suitably inserting the oscillograph in the exciter circuit.* On the other hand, an examination of Fig. 6 would lead us to expect six more or less sudden irregularities or excrescences per half-wave of the curve representing total threading of magnetic flux † by the armature coils. This does not mean a 12th

* I have tried this experiment under difficulties, and certainly detected slight and rapid periodic fluctuations in the exciting current. The experiment is well worth repeating, however, my results being by no means conclusive.

† By threading of magnetic flux I wish to indicate the sum total of magnetic flux interlinked with each turn of the armature winding.

harmonic; an even harmonic would be impossible with such a generator—it would mean that the positive half-wave was of a different shape from the negative half, and the right-hand half of each half-wave was of a different shape from the left-hand half. This, of course, with such a generator is impossible.*

If, however, we consider a smooth wave (not necessarily a sine wave) with 6 ripples per half-period superimposed in the manner indicated in Fig. 6A so that the ripples are wholly positive during the positive half-period and wholly negative during the negative half-period, we

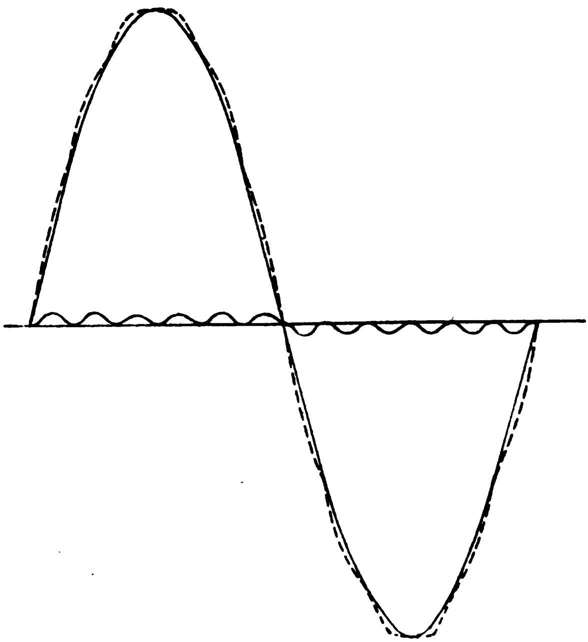


FIG. 6A.

should get a curve such as we might reasonably expect with a 12 slot per period alternator. This curve of total threading of magnetic flux would be quite symmetrical, and would possess 12 irregularities corresponding to the number of teeth.

It is therefore instructive to study this case, and to simplify matters we will assume that the ripple between o and π can be represented as

* In making this statement I am leaving out of account all extraneous effects, such as hysteresis in the armature teeth, cross magnetisation, etc. Later on we find curves in which the right and left halves are different owing to some such effects, in all probability. I mean here that, provided the winding, slots, pole-pieces, etc., are symmetrical, the process of the flux cutting into an armature coil must be the exact reverse of cutting out of a coil; moreover, the flux from an S-pole must of necessity cut in and out in the exact manner as does the flux from the N-pole.

a (1 — cos 12 $k\,t$) and between π and $2\,\pi$ as $-a$ (1 — cos 12 $k\,t$). The fundamental term is F N sin $k\,t$ (F N being the maximum interlinkage of flux with armature winding).

Now, we can quite easily split this up into a Fourier's series; the amplitude of the p^{th} sine term will be proportional to *—

$$f_1(\pi) - f_1(o),$$

and of the p^{th} cosine term to—

$$f_2(\pi) - f_2(o).$$

Where $f_1\,(k\,t)$ represents—

$$\int (1 - \cos 12\,k\,t) \sin p\,k\,t\;dt \text{ or } -\frac{1}{p\,k}\cos p\,k\,t + \frac{\cos(p+12)\,k\,t}{2\,(p+12)\,k} + \frac{\cos(p-12)\,k\,t}{2\,(p-12)\,k}.$$

and $f_2\,(k\,t)$ represents—

$$\int (1 - \cos 12\,k\,t) \cos p\,k\,t\;dt \text{ or } \frac{1}{p\,k}\sin p\,k\,t - \frac{\sin(p+12)\,k\,t}{2\;p-12)\,k} + \frac{\sin(p-12)\,k\,t}{2\,(p-12)\,k}.$$

If p is even, $\cos(p \pm 12)\,\pi = +1$.
If p is odd, $\cos(p \pm 12)\,\pi = -1$.
If p is odd or even, $\sin(p \pm 12)\,\pi = o$.

$$\therefore\; f_1(\pi) - f_1(o) \propto \left(\frac{1}{p} - \frac{p}{p^2 - 144}\right) \text{ where } p \text{ is odd,}$$
$$f_1(\pi) - f_1(o) = o \qquad \text{,, even,}$$
$$f_2(\pi) - f_2(o) = o \qquad \text{,, odd or even.}$$

This shows us that in this expansion the odd harmonics only enter in, and they are all *sine* terms.

Now, $p/(p^2 - 144)$ becomes infinite when $p = 12$, as p can only have odd integral values we see that the 11th and 13th harmonics are the most important.

The relative amplitudes of the harmonics in the expression for E.M.F. are obtained from those representing total interlinkage of flux by multiplying by the corresponding order of harmonic. This has been represented in the following table:—

	Flux.		E.M.F.
7th Harmonic,	$\frac{1}{7} + \frac{7}{95} =$	·215	1·50
9th ,,	$\frac{1}{9} + \frac{9}{63} =$	·253	2·27
11th ,,	$\frac{1}{11} + \frac{11}{23} =$	·568	6·24
13th ,,	$\frac{1}{13} - \frac{13}{25} =$	− ·444	− 5·77
15th ,,	$\frac{1}{15} - \frac{15}{81} =$	− ·119	− 1·78
17th ,,	$\frac{1}{17} - \frac{17}{145} =$	− ·059	− 1·00

* The full expression is, of course—
$\left\{f_1(\pi) - f_1(o)\right\} + \left\{-f_1(2\,\pi) + f_1(\pi)\right\}$ which in our case is $2\,[f_1(\pi) - f_1(o)]$.

We may say generally that the most important harmonics where there are q teeth in the generator per pair of poles are the

$$(q - 1)^{th} \text{ and the } (q + 1)^{th},$$

unless indeed the grouping of the armature conductors is such as would naturally introduce other harmonics of important magnitude, independent of whether the armature be smooth or not.

The question now arises whether 12 ripples in the D.C. voltage per cycle are consistent with an 11th and 13th harmonic. I think so. If we consider the 13th harmonic occurring similarly in the three phases, A, B, C, then the harmonic in phase B will be 120 deg. of its own period in advance of the harmonic in A. Similarly the harmonic in C will be in advance of that in B by 120 deg. This means that we have a true "three-phase ripple" advancing in the same direction as the main wave, but with 13 times the velocity. Now, look at the 11th harmonic; in phase B it will be 2/3 period in advance of that in A; similarly C will be 2/3 period in advance of B. This, again, will form a "three-phase ripple," but retreating this time with 11 times the velocity of the main wave. What does this mean in the rotary converter? The armature is rotating, say, at n revolutions forwards; the three-phase current in it produces a backward rotating field of speed n relative to the armature, or at rest relatively to the field system. The 13th harmonic, travelling 13 times as fast and in the same direction, corresponds to a rotating field revolving at a speed of $(13 - 1)$ times that of the armature relative to the fixed position of the brushes, while the 11th harmonic produces a field rotating in the opposite direction, and therefore with $(11 + 1)$ times the speed of the armature relatively to the fixed frame of the rotary.

Both of these harmonics will therefore have the effect of producing 12 ripples per cycle in the D.C. voltage. The same argument could not be applied to the 17th, 19th, or any other harmonics; if, therefore, for any reason these predominate, we should expect the D.C. voltage line to be somewhat broken and jagged. In this connection refer to Curves X and XII, and compare also the undulating voltages.

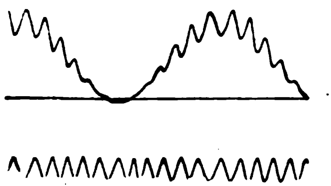
Again, if we assume that (due to the changing magnetic reluctance of the circuit as the pole assumes different positions relatively to the armature teeth) fluctuations in the total magnetism emerging from the polar surface are introduced, we can imagine that the field system is giving a rise to a constant, plus an alternating, flux. This alternating flux will have a frequency of q where $\sim$ equals the frequency of the generator. This alternating flux is, moreover, equivalent to two rotating fluxes rotating forwards and backwards with q times the velocity of the field system. If we add the rotation of the field system, we have a main or fundamental field rotating at, say, unit speed, a forward rotating field at $q + 1$, and a backward rotating field at a speed of $q - 1$. Hence variation of total flux will likewise give rise to the 11th and 13th harmonics.

We now come to the question of the magnification or accentuation of the harmonics. This can be brought about, in my opinion, in two entirely distinct and separate ways:—

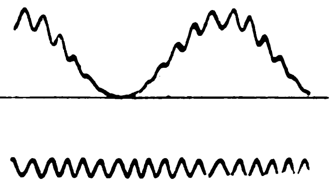
(1) By strongly magnetising the teeth in the armature by the armature currents themselves;

(2) By resonance, pure and simple.

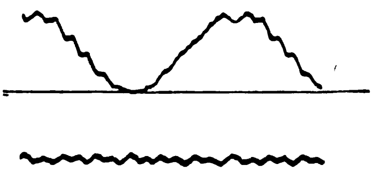
These two causes produce results of a very similar nature, but each phenomenon appears to require a totally different explanation.



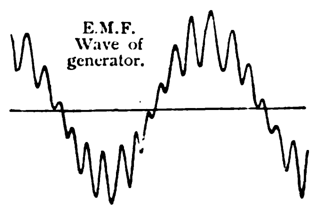
CURVE X.—A.C. and D.C. E.M.F. of Rotary. Generator supplying 140 amps., lagging current.



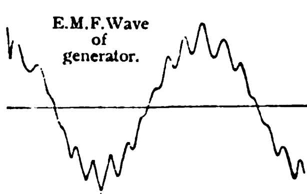
CURVE XI.—A.C. and D.C. E.M.F. of Rotary. Generator supplying 25 amps., 7 rotaries running on no load, normal excitation, 93,700 yards of cable connected.



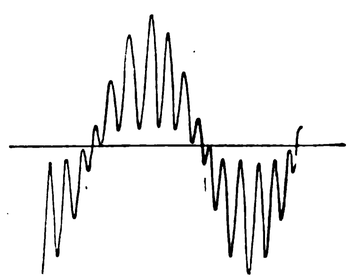
CURVE XII.—A.C. and D.C. E.M.F.'s. One rotary running with normal excitation, 93,700 yards of cable connected.



CURVE XIII.—Rotaries on no load, under-excited, 195 amps., lagging at power station.



CURVE XIV.—Rotaries on no load over-excited, 185 amps., leading at power-station.



CURVE XV.—E.M.F. Wave of Generator on no load, cables adjusted for partial resonance with 13th harmonic.

Examine Curves XIII., XIV., XV. In the first case, a lagging current,' nearly equal in amount to the full-load current of the generator, was being given out.

Now, a lagging current involves a very strongly-excited field system in the generator. The armature current will be of a demagnetising order, and will produc its maximum effect when the pole is in the

most favourable position for the magnetisation of the teeth within the coil.

A leading current, on the other hand, involves a weakly-excited field system, the armature currents augmenting the magnetism due to the field winding; again the pole is in a favourable position for the magnetisation of the teeth by the armature currents.

It appears, curiously enough, that the lagging current produces the greater magnification of the harmonics, but that practically the full-load current is necessary to produce this effect to any great extent. Turn now to Curve XV. A few cables only were in circuit, and the current flowing out of the generator was too small to be read on the station instruments. This was a case of resonance.

I would here ask pardon for digressing into the elementary theory of electrical resonance for the benefit of any present who may not have had occasion to consider the subject.

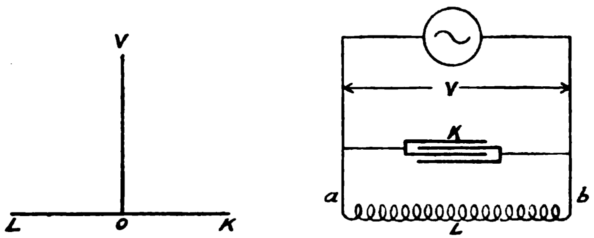


FIG. 7.

The current flowing into a condenser may be expressed in effective amperes by

$$2 \pi n K V \quad \ldots\ldots\ldots\ldots \quad (7)$$

where n = frequency of the circuit;
„ K = capacity of condenser in farads;
„ V = effective volts.

Again, if L be the coefficient of self-induction of a coil, the current passing through it will be expressed by

$$\frac{V}{2 \pi n L} \quad \ldots\ldots\ldots\ldots \quad (8)$$

V being the effective volts at its terminals.

If we equate (7) and (8) we get the condition under which the capacity current equals the self-induction current, V being the same in each case. This condition is

$$(2 \pi n)^2 = \frac{1}{L K}. \quad \ldots\ldots\ldots\ldots \quad (9)$$

Let us suppose that we have a pure self-inductiòn and a pure capacity connected in parallel, as in Fig. 7.

Let the alternating E.M.F. V be represented by the vector O V; we know that the capacity current will be 90 deg. in advance of O V, that is

in position O K; we also know that current flowing through the self-induction will lag behind O V by 90 deg. This is represented by O L.

If now equation (9) holds, O K = O L, and the resultant of these currents as far as the outside circuit is concerned, is zero at every instant. We have then the case of a combination, of which the terminals are *a* and *b*; when this combination forms part of a closed circuit in which an alternating E.M.F., of frequency *n* and value *v*, is generated, no current circulates on the outside circuit *a c b*, and the potential difference between *a* and *b* is V. These are the conditions which would hold if the combination were removed and a perfect insulator substituted. We may therefore say that this combination at this particular frequency behaves, as far as the outside circuit is concerned, as a perfect insulator.

Now, introduce resistance *r* into each arm of the combination, and modify the diagram to suit, Fig. 8.

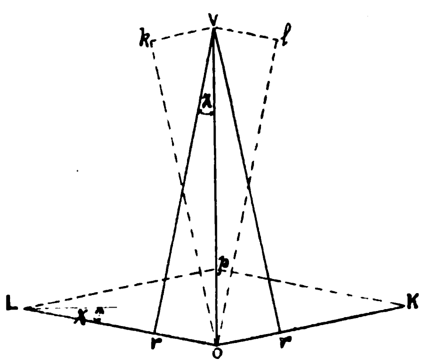


FIG. 8.

O L and O K will not now lag and lead by quite 90 deg.; in each case we have an ohmic drop O *r* in phase with the current, and an E.M.F. O *l*, O *k* at right angles, such that the resultant with the corresponding ohmic drop is O V.

The current in the outside circuit will be O *p*, which is equal to

$$2 \times \mathrm{O\,L} \sin \chi \text{ ; or } 2\,r\,\frac{\mathrm{O\,L}^2}{\mathrm{O\,V}}$$

and will be in phase with O V. The combination therefore will behave as though it had an ohmic resistance of

$$\frac{\mathrm{O\,V}^2}{\mathrm{O\,L}^2} \times \frac{1}{2\,r}.$$

Now, $\mathrm{O\,V}^2 = \mathrm{O}\,l^2 + \mathrm{O}\,r^2$; $\mathrm{O}\,l^2 = (2\,\pi\,n\,\mathrm{L})^2\,\mathrm{O\,L}^2$, and from (8) and (9) we can write $\frac{1}{\mathrm{L\,K}}$ for $4\,\pi^2\,n^2$,

hence $\mathrm{O\,V}^2 = (\frac{\mathrm{L}}{\mathrm{K}} + r^2)\,\mathrm{O\,L}^2$ ∴ the resistance is $\frac{\mathrm{L}}{2\,\mathrm{K}r} + \frac{r}{2}$.

Let us take an example and put $L = 1$ secohm, $K = 1$ microfarad, $r = 1$ ohm, then the resistance of the combination will be 0·5 megohm; thus we see that if the capacity and self-induction be not pure, but contain also a small amount of ohmic resistance, the combination behaves towards the outside circuit at the particular frequency as an imperfect insulator, but nevertheless of high insulation resistance. If in this particular case we make the further condition that

$$\frac{L}{2\,Kr} + \frac{r}{2} = r \text{ or that } K = \frac{L}{r^2},$$

the combination is equivalent to an effective resistance of r ohms, and this will as a matter of fact be true not only for sine waves of the one particular frequency, but universally for any periodic or unperiodic function which expresses the change of V; in fact, under these circumstances the current in the outside circuit is always V/r.

We have now to consider a perfect self-induction in series with a perfect capacity, and the same current C passing through each. This modifies the diagram shown in Fig. 7 somewhat.

If we turn O L through 90 deg. forward, the E.M.F. required to overcome self-induction will be O V_L; if we turn O K back through

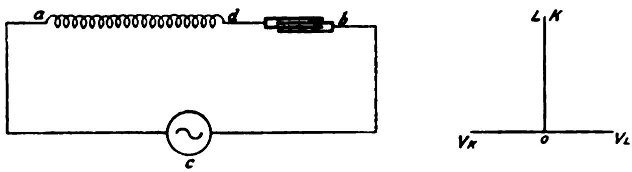


FIG. 9.

90 deg. to concide with O L, the voltage vector will take the position O V_K; see Fig. 9.

This diagram represents the state of things when the same current flows through capacity and self-induction, and the current is at its maximum.

If, therefore, the current is C, and is represented by the vector O L and O K, the potential difference between a and d will be the vector O V_L and between d and b the vector O V_K; therefore between a and b the potential difference will be the sum of O V_L and O V_K, which is at every instant zero. We are therefore sending a definite current through the combination, although no potential difference between the terminals a and b is necessary. The combination, therefore, behaves, as far as the outside circuit is concerned, at this particular frequency as a perfect conductor. I am indebted to Mr. R. C. Clinker for the notion of a perfect insulator and perfect conductor here introduced. The current strength in the circuit $a\,c\,b$ will be determined by the resistance of this portion of the circuit and the E.M.F. induced in it. If the resistance be low, the current will rise to a correspondingly high figure.

Now, although the potential difference between a and b is zero, we know that that between a and d or d and b is given by equations (7) and (8). Let us therefore imagine the E.M.F. E acting in the circuit, the self-induction short-circuited, and the current measured to be c; then, if the capacity be short-circuited instead of the self-induction, we shall have again the current c flowing.

If both be short-circuited we shall have a current of E/ρ where ρ = resistance of portion $a\,c\,b$. Now, E/ρ may be 10, 100, 1000, etc., times c, just depending on the value of ρ. But if both self-induction and capacity remain unshort-circuited, the same current will flow as if short-circuited; hence, in the former case the potential difference $a\,d$ or $a\,b$ will be approximately 10, 100, 1000 times E, as the case may be, just depending on the ratio of E/ρ to c. This is what is known as electrical resonance, when the combination of self-induction and capacity acts like a perfect conductor, or a nearly perfect conductor, as far as the outside circuit is concerned, there being, however, a rise of potential within the combination equal to $C\sqrt{\frac{L}{K}}$.

Of course, if we consider the self-induction as possessing resistance r,

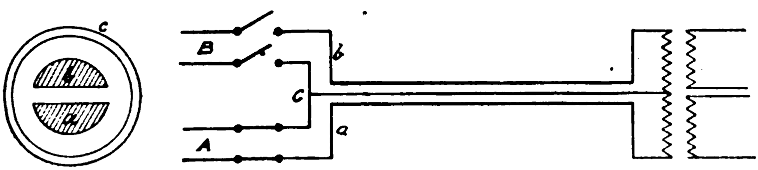


FIG. 10.

and the capacity also the same resistance, the combination will behave as an imperfect conductor with ohmic resistance $2\,r$ ohms, *i.e.*, the potential difference between a and b will be $2\,r$C and in phase with C.

In alternating electric supply circuits we often have to deal with self-inductions and capacities which would check the current down to the same values if the same E.M.F. were applied to each, which is the necessary condition for resonance; consider, for example, a two-phase cable with two insulated cores within a common outer as return; see Fig. 10.

Suppose phase B in the power-house has been opened, and consider the state of things that exists; we can represent it as shown in Fig. 11. Current enters conductor a, and returns by conductor c; it can flow through the capacity $a\,c$, and the self-induction $a\,c$, these being in parallel; but an alternative path is through capacity $a\,b$, and thence through capacity $b\,c$ in parallel with self-induction $b\,c$.

Suppose the frequency is 25, the voltage per phase = 3000 volts, the transformers at the end of the line 150 kw. each, and such as to take a magnetising current of 2 per cent. of full-load current or one ampere; secondary circuits are open. Let the capacity between either conductor a or b and sheath, the other conductor being grounded

be ·75 mf. per mile, and between a and b together, and sheath ·9 mf. per mile, *i.e.* cap: $(a + c), b =$ ·75, and cap: $(a + b), c =$ ·9 mf. per mile, then we have a capacity effect equivalent to that shown in Fig 11. Let the length of line be 2·83 miles, then the total capacity $a\ c, =$ 1·27 mf. and total capacity $a\ b, =$ ·847 mf. If now the potential difference between b and c is V_1, the current through the transformer $b c$ is $V_1/3000 = 3{\cdot}33 \times 10^{-4} V_1$, and through the capacity $b\,c$, $2 \times 10^{-4} V_1$. The current arriving at b will therefore be a wattless current,

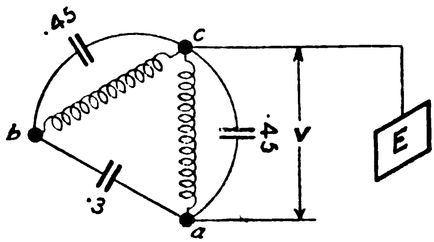


FIG. 11.

lagging 90 deg. between the E.M.F. and equal to $1{\cdot}33\ 10^{-4} V_1$. But if the difference of potential between a and b is V_1, we have again a capacity current through $a\,b$ of $1{\cdot}33\ 10^{-4} V_1$.

Thus we have the necessary conditions for resonance, and the potential of the switched-out conductor b will rise until the insulation somewhere in the cable gives way and modifies the conditions. This has merely been given as an example; there are, of course, a large number of combinations possible where resonance might occur, and

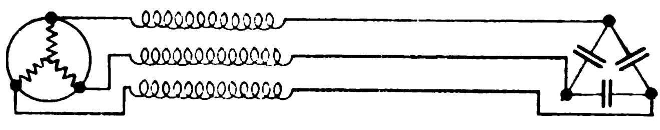


FIG. 12.

every station engineer is more or less on the alert for them. A most interesting paper on the subject of high-tension cable breakdowns from resonance effects appeared in the "Electrotechnische Zeitschrift" on 28th December, 1899, by Mr. Gisbert Kapp, and was translated by the present writer for the *Electrical Review*, and appeared in the 9th and 23rd March issues of that paper in 1900.

Now, every alternator possesses reaction and self-induction. By reaction I usually mean that the armature currents produce magnetic lines which thread through the magnetic path in the field system, either weakening or strengthening it, according as the armature ampere-turns assist or oppose the field system magnetising force. The term self-induction I usually apply to those lines of force generated by

the armature currents which do not produce an alteration of the total flux in the field system, but which close round the armature windings without including the field-magnet windings. Both of these effects are more or less proportioned to the strength of the armature currents, and result in an alteration of the magnetism threading the armature windings. This diminution or increase, as the case may be, induces an E.M.F. in quadrature with the current, and may therefore be looked upon as a self-induction.

Every alternator, therefore, may be represented by an imaginary machine producing an alternating E.M.F., without self-induction and without reaction, but with a choking coil in series with it. Unfortunately, as we shall see later, it is necessary to consider the choking coil as having a variable coefficient of self-induction, which is however, a periodic function of time. We may thus represent a three-phase alternator connected to a cable as in Fig. 12.

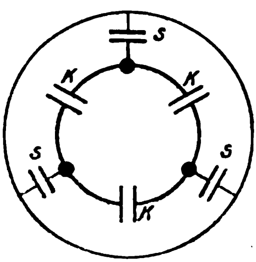


FIG. 13*a*.

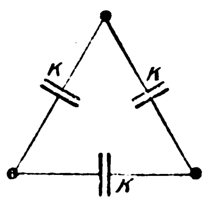


FIG. 13*b*.

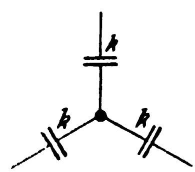


FIG. 13*c*.

In talking of the self-induction of an alternator, I shall for the purpose of this paper include in the term the armature reaction, *i.e.*, I shall refer to that self-induction (whether with constant or variable coefficient) which inserted in series with a reactionless and self-inductionless machine would give the same characteristics.

The capacity of a three-phase three-core lead-sheathed cable may be considered as a combination of capacities, as in Fig. 13 (*a*).*

A three-phase Δ capacity as shown in Fig. 13 (*b*) will take the same current per line wire as a Y capacity as in Fig. 13 (*c*) if $K = \frac{k}{3}$.

We do not in practice meet cases where the self-induction of

* We are justified in assuming the capacity effect of a multiple core lead-sheathed cable can be exactly represented by actual capacities between the individual conductors. and between the conductors and lead sheath, for taking the case of a three-core cable, we know that if Q_1 Q_2 Q_3, V_1 V_2 V_3 represent the charges and potentials of the various conductors, the lead sheath being grounded, we have the relations—

$$Q_1 = a_{1\text{-}1} V_1 + a_{1\text{-}2} V_2 + a_{1\text{-}3} V_3 \quad . \quad . \quad . \quad . \quad . \quad (10)$$

and similarly for Q_2 and Q_3, where the *a* coefficients are constants of the same dimensions as capacity.

Now, if we consider capacities $K_{1\text{-}2}$ $K_{1\text{-}3}$ $K_{2\text{-}3}$ connected between the con-

the alternator will produce resonance with the capacity of the cable system at the fundamental frequency. For example, taking a large three-phase cable system as represented by a three-legged capacity of 5 mf. per leg, the capacity current per leg at 6,500 volts per phase, 25 cycles would be 2·95 amperes. Fig. 14.

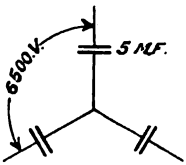


FIG. 14.

The self-induction in the alternator which would produce resonance with this cable system would therefore be such as would only allow 2·95 amps. per leg to circulate when the generator was excited to 6,500 volts, and short-circuited. Such an alternator would be manifestly inadequate in connection with such a cable system, but might perhaps

ductors, and $K_{1\cdot s}$ $K_{2\cdot s}$ $K_{3\cdot s}$ connected between the conductors and sheath, we have :—

$$Q_1 = K_{1\cdot 2}(V_1 - V_2) + K_{1\cdot 3}(V_1 - V_3) + K_{1\cdot s} V_1 \quad . \quad . \quad (11),$$

and similarly with Q_2 and Q_3.

This can be written as—

$$Q_1 = (K_{1\cdot 2} + K_{1\cdot 3} + K_{1\cdot s}) V_1 - K_{1\cdot 2} V_2 - K_{1\cdot 3} V_3.$$

$$\begin{aligned} \text{Hence} \quad a_{1\cdot 1} &= K_{1\cdot 2} + K_{1\cdot 3} + K_{1\cdot s} \\ - a_{1\cdot 2} &= K_{1\cdot 2} \\ - a_{1\cdot 3} &= K_{1\cdot 3}, \text{ and so on.} \end{aligned}$$

We therefore see that (11) is only another way of writing (10); if then we determine $K_{1\cdot 2}$ $K_{1\cdot 3}$ $K_{1\cdot s}$, etc., by experiment, we can consider these as actual capacities connected as represented by eq. (11).

Owing to symmetry in a three-core cable we can write—

$$K_{1\cdot 2} = K_{1\cdot 3} = K_{2\cdot 3} = K$$

$$\text{and} \quad K_{1\cdot s} = K_{2\cdot 3} = K_{3\cdot s} = S.$$

Now, if 2 and 3 be earthed, we have—

$$Q_1 = (2K + S) V_1 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (12).$$

If 2 and 3 be connected together but not earthed, and if they together have an equal and opposite charge to that on 1, we have—

$$Q_1 = (2K + S) V_1 - 2K V_2$$

$$Q_2 = (K + S) V_2 - K V_1 = -\frac{Q_1}{2}$$

$$\therefore \quad V_2 = -\frac{V_1}{2}, \text{ and } Q_1 = \left(2K + \frac{2}{3} S\right)(V_1 - V_2) \quad . \quad . \quad . \quad (13).$$

Lastly, if 3 be left insulated without charge, and if the charge on 2 be equal and opposite to that on 1, we have—

$$\begin{aligned} Q_1 &= (2K + S) V_1 - K(V_2 + V_3) \\ V_2 &= -V_1 \\ \text{and} \quad O &= (2K + S) V_3 - K V_1 - K V_2, \textit{ i.e.}, V_3 = O. \end{aligned}$$

This gives—

$$Q_1 = (3K + S) V_1 = \left(\frac{3}{2} K + \frac{S}{2}\right)\left(V_1 - V_2\right) \quad . \quad . \quad . \quad (14).$$

If, therefore, we measure Q and the P.D. in any two of these cases, we have all particulars necessary for the determination of the capacity constants of the cable, and can treat these as if they were actual capacities connected as shown in Fig. 13(a), where the centre point is the lead sheath.

We shall have occasion to make use of (12), (13), and (14), a little later.

be used for applying a pressure test to the cables, in which case, of course, the greatest care would have to be exercised.

Although the self-induction of the supply alternator will not produce resonance at the fundamental frequency, it does not at all follow that such may not occur, due to a higher harmonic of the E.M.F. The current which a given capacity will take at a given voltage is proportional to a frequency, while the current which a self-induction will pass at the same voltage is inversely proportional to the frequency.

In the above case the capacity current per 1000 volts corresponding to the 11th harmonic would be 8·65 amps. A self-induction which would pass 8·65 amps. at 1000 volts 275 cycles per second would pass 356 amps. at 3,750 volts and 25 cycles, or an alternator with this self-induction per leg would give on short-circuit 356 amps. per leg when excited to 6,500 volts per phase. (I have chosen this figure, because it nearly corresponds with the results taken from the 2,500 kw. generators in Glasgow.) We should therefore at first sight expect to obtain resonance with such an alternator, and a cable system corresponding to Fig. 14, if an 11th harmonic existed in the E.M.F. wave.

I made some experiments to determine the capacity of the cables, by inserting a hot-wire ammeter in circuit, but I obtained strangely inconsistent readings; I therefore forbear to give them.

Mr. R. C. Clinker made some tests on similar cables for the Central London Railway, and obtained the following results per mile :—

1. From one core to other two cores + lead sheath = ·38 mf.

2. From one core to other two cores, sheath disconnected and earthed = ·32 mf.

3. From one core to one other core, 3rd-core insulated, sheath disconnected and earthed = ·23 mf.

If K be the capacity from core to core, and S the capacity from core to sheath, and assuming the insulation of both poles of the testing circuit to be so good that all leakage currents were negligible in comparison with the capacity currents, we see that we have :—

$$\text{By test (1) } 2\,K + S = \cdot 38$$
$$\text{,, (2) } 2\,K + \frac{2}{3}S = \cdot 32$$
$$\therefore S = \cdot 18 \qquad K = \cdot 1$$

and by test (3) we have a capacity of

$$\frac{3}{2}K + \frac{S}{2}.$$

Which with above values of K and S equals ·24 as against ·23 actually measured.

The above cable is therefore equivalent to a Y capacity of ·48 mf. per leg per mile, and therefore 10·4 miles would give the capacity represented in Fig. 14.

As a matter of fact, I find considerably more cable is needed to produce resonance, and I think this is probably due to the fact that the coefficient of self-induction of the alternator is by no means the same for the fundamental as for the higher harmonics.

We know that the coefficient of self-induction of such a machine varies between wide limits, it must depend on the relative position of field system to armature coils, and also on the value of the armature current in each position. Fig. 15 represents what is known as the curve of synchronous impedance of the Glasgow alternators; or the short-circuit armature current, in terms of armature volts on open circuit with the same field excitation at synchronous speed.

In the first place, it is clear that by this method the self-induction should be a maximum, since the poles are in the most favourable position when the armature currents are at their maximum. Next, we see that even this method does not give a constant coefficient. If we take the area of one-half period of the E.M.F. wave as proportional to the square root of the mean square, and the maximum of the current as proportional to the R.M.S., which would be correct

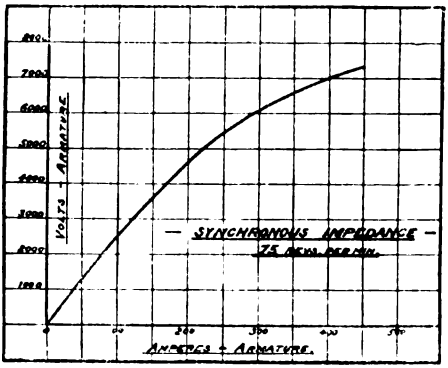


FIG. 15.

assumptions if we were dealing with sine functions, then the volts would be proportional to, or represent maximum flux, and current, the maximum current producing such flux, in which case the slope of the synchronous impedance curve represents $\frac{dN}{dC}$, where N is the total flux produced by the current C.

Now $\frac{dN}{dC} = \frac{dN}{dt} \cdot \frac{dt}{dC}$, therefore the slope which we will call $\tan\theta$ is such that

$$p \tan\theta \frac{dC}{dt} = \frac{dN}{dt} \left(\text{or } L\frac{dC}{dt} = E\right),$$

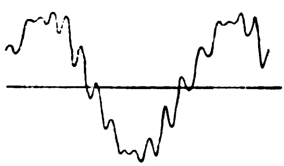
which means that $\tan\theta$ at every point of the curve is proportional to the coefficient of self-induction for that particular current strength.

Fig. 15 shows that this varies between the limits of 1·3 at low currents and 0·5 at 300 amperes.

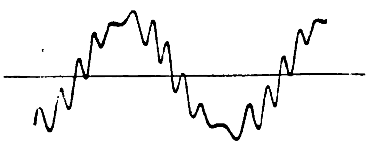
We see then that the coefficient of self-induction has a different value for each ripple on the E.M.F. wave, due to the position of

the field system; and, again, when a heavy armature current is being generated, the coefficient is further modified by the degree of magnetic saturation of the armature. The resultant of these two effects must depend largely on the power-factor of the circuit, and will be an extremely complicated function to express.

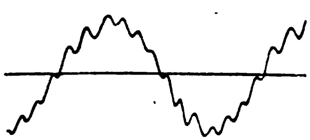
If we examine Curves XVI. and XVII. we see that with 93,700 yards of cable in circuit we obtain the 11th harmonic accentuated; with somewhat less cable in I have obtained resonance due to the 11th harmonic, but could not obtain a photographic record. Curves XVI. and XVII. were taken with about twelve months' interval. The first was traced by hand; the second photographed. I cannot vouch for the engine speed being exactly the same in each case. On reducing the capacity I brought the 13th harmonic gradually into prominence (see Curves XVIII., XIX., and XV.). It is very difficult



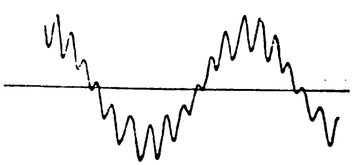
CURVE XVI.—No Load E.M.F. Wave. 93,700 yards of cable connected.



CURVE XVII.—No Load E.M.F. Wave. 93,700 yards of cable connected.



CURVE XVIII.—No Load E.M.F. Wave. 71,200 yards of cable connected.



CURVE XIX.—E.M.F. wave. 51,800 yards of cable connected.

to obtain good results under these circumstances, for if resonance be too pronounced the oscillograph motor stops, and the results cannot be noted. I do not think that Curve XV. shows the conditions of maximum resonance by any means; in fact, I have had instantaneous glimpses of alarming resonance, but for the reasons already stated I could not reproduce them.

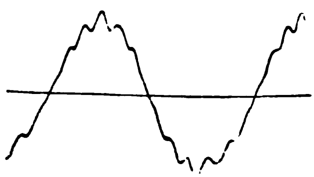
I used to think it a safe procedure when shutting down to gradually slow up the main engine and let the voltage die down gradually; similarly it was my opinion that one should excite the generator, and run up slowly on the cables when starting up, but from these experiments it is clear that by so doing one passes through the conditions for maximum resonance with all odd harmonics above the 11th. Undoubtedly the better procedure is to run the machine up to full speed, and then slowly to bring up the excitation to the normal, and to reverse the procedure when shutting down.

Curves XX. and XXI. more nearly approach to the E.M.F. curve of the alternator on open circuit.

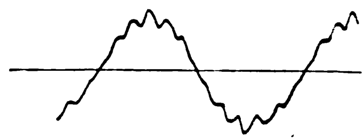
Another important point to consider is whether resonance due to a higher harmonic can occur under load conditions. The curves generally indicate that this is not so, the ripples being apparently damped down to a minimum under load conditions.

Curve XXII., which was taken at half normal load, shows, however, certain ripples accentuated, and the question is worth inquiring into.

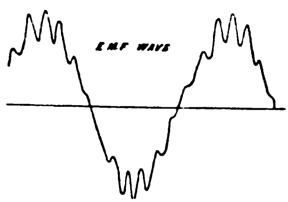
Look at Curve XXIII. We have already seen that the back E.M.F. of the rotaries being a smooth curve, the higher current harmonics in the system are wattless, and are either capacity or self-induction currents. The current ripples which flow into the rotaries, representing self-induction currents, no doubt partly neutralise the capacity of the system, but at the high frequencies



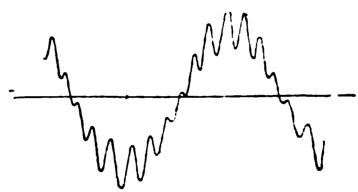
Curve XX.—No Load E.M.F. Wave. 9,150 yards of cable connected.



Curve XXI.—E.M.F. Wave. 2,290 yards of cable connected



Curve XXII.—Taken at substation C as load falls off between 11–12 p.m., 125 amps. at power-station.



Curve XXIII.—E.M.F. Wave Rotaries on no load (normal excitation), 20-30 amps. at power-station.

we are dealing with it is impossible that the whole capacity effect can be thus neutralised, and we have at such frequencies as 275 and 325 cycles a balance of capacity effect left over; it is then merely a question of the number of rotaries, transformers, and cables in service which decides whether or not partial resonance will occur under load conditions.

In this connection it must be borne in mind that if r is the ratio of transformation of the transformers (in the case in question $r = 20$), a coefficient of self-induction in the low-tension side is equivalent to r^2 ($= 400$) times the coefficient of self-induction in the high-tension side. When, again, we compare the capacity and self-induction currents (for the same voltage applied) at a high frequency, such

as the 13th, and remember that the former varies directly, and the latter inversely as the frequency, we see that even a large wattless current in the low-tension side, due to self-induction at the fundamental frequency, can have but a small effect in neutralising the capacity effect of the cables at the high frequency. This is easily calculated out.

From the foregoing, it is evident that it should be easy in any particular case to determine experimentally what conditions of capacity, etc., will give maximum resonance.

For example, if we know the length (l) of cable which produces resonance with the p^{th} harmonic, one generator only working, at the speed s revolutions per minute, we know that the length which will give resonance, with the q^{th} harmonic at a speed s, will be $l\left(\frac{p}{q}\frac{s}{s_1}\right)^2$; again, if two generators be thrown in parallel, we halve thereby the inductance of the circuit, and therefore resonance with the same harmonic will only occur with twice the amount of cable connected to the circuit.

This fact alone will usually prevent important resonance effects under full-load conditions, the period of greatest importance from this point of view being that of light load, where the cable system is being fed from one generator which is perhaps of relatively small proportions.

It must not be supposed that I attach great practical importance to the above considerations of the possibility of the occurrence of resonance; as a matter of fact, although in Glasgow, I was for a long time unaware that anything of the kind could be going on, we experienced no difficulty at all, and it is the general opinion of a great many experienced engineers with whom I have spoken on the subject that resonance is not to be generally feared in ordinary well-laid-out systems.

I *do*, however, consider it important for each engineer, as far as possible, to be conversant with the conditions under which resonance is likely to occur in the system under his charge, and to avoid the combination if it is at all likely to be serious.

It is further conceivable that slight resonance effects might occur in cable circuits supplied by continuous-current machines. All such dynamos have a ripple of a high order present in their E.M.F. In the case of a rotary converter this ripple may, as we have seen, be pronounced, and I think it possible that considerable resonance effects might be found in such cases. It would be interesting to look for them.

PART II.

The second part of this paper is descriptive of some experiments I carried out to examine optically the more temporary or non-periodic effects in electric circuits, by which I mean such effects as the growth of the current in a continuous-current circuit containing self-induction, or the oscillatory nature of the charge current of a

cable when switching it on to a direct- or alternating-current circuit, and other similar effects. I am perfectly aware that these phenomena are treated mathematically in the various text-books on the subject, but I still think the experiments highly instructive.

In order to render these results visible on the desk of the oscillograph, it was necessary to make them occur periodically and synchronously with the motor of the oscillograph. I therefore constructed a contact maker, and attached it to the shaft of a disused tramway motor, which had already been provided with two slip rings for other purposes. The motor was supplied with direct current, the oscillograph motor connected to the slip-rings, and the strips suitably connected to the contact maker. The latter consisted of a continuous ring, and a second one cut into sixteen equal parts

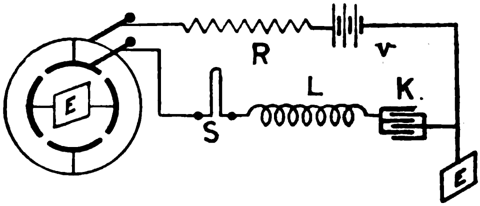


FIG. 16*a*.

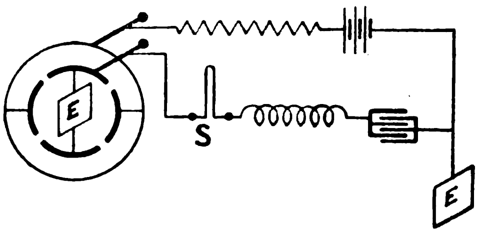


FIG. 16*b*.

with provision for connecting them up in any way desired. The motor having four poles, I connected the contacts in four groups of four, and used this arrangement throughout.

Figure 16 (*a*) and (*b*) shows my general arrangement.

In position (*a*) it will be seen that the charge current for the combination of capacity and self-induction passes through the oscillograph strip S; in position (*b*) the combination discharges through S; this process, occurring synchronously with the vibrations of the oscillograph mirror, appears as a stationary curve and can be photographed as heretofore. The photographs, which I here reproduce, had an average of 30 seconds exposure.

Curve XXIV. represents an ordinary make and short-circuit without self-induction or capacity.

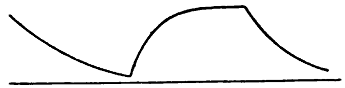
Curve XXV. represents the growth of the current in a circuit containing a transformer on open circuit.

Curve XXVI. represents the above, but with half of the high-tension winding short-circuited through a single lamp.

Curve XXVII. represents the same, but with the whole high-tension winding short-circuited through the incandescent lamp.

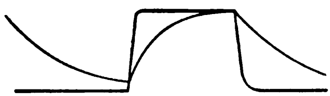
The annihilation of the self-induction due to the short-circuited secondary is noteworthy. I have used the curves thus photographed for the determination of the coefficient of self-induction of a circuit;

CURVE XXIV.—R = 24·25 ohms, L = O, K = O, R.P.M. = 750, V = 2·6 volts.



CURVE XXV.—R = 24·4 ohms, L = transformer H.T. open, K = O, R.P.M = 760, V = 3·9 volts.

CURVE XXVI.—Same as XXV., but with half H.T. winding short-circuted.



CURVE XXVII.—Same as XXV., but with whole of H.T. winding short-circuited.

it will be noticed it gives the value of the coefficient of self-induction for practically zero current, since the current through the oscillograph should at no time exceed 0·1 ampere. As such, the method may prove useful to others who have an oscillograph at their disposal, and I will therefore illustrate it briefly.

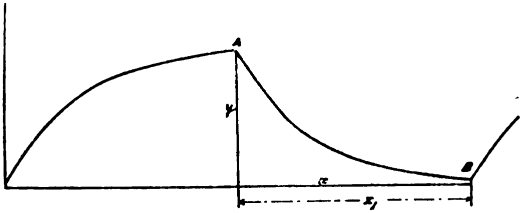


FIG. 17.

We know that the law of curve from A to B, Fig. 17, is

$$y = k\epsilon^{-px},$$

y and x representing distances only, and being measured to the same scale.

We have then that $\dfrac{d(\log_\epsilon y)}{dx} = -p$; in other words, if we measure y for each value of x from the curve, and plot $\log_\epsilon y$ and x to the same scale, we should obtain a straight line not passing through the origin, and with a negative slope equal to p.

But we know that $p\,x_1 = \frac{R}{L}\,t_1$* ; t_1 being the time occupied by the discharge from A to B. $\therefore$ L in secohms $= \frac{R\,t_1}{p_1\,x_1}$ R being in ohms, and t_1 in seconds.

t_1 is of course easily determined by the speed of revolution of the contact maker. In my experiments, t_1 was $\frac{1}{50}$th second. It is to be noticed that the constant of the oscillograph or deflection per ampere does not enter in.

It may be urged that where y is very small it will not be possible to measure it accurately. This is true ; the curve of discharge is really asymptotic to the zero line, log 0 equals $-\infty$, hence if we take the zero line the smallest amount too high or too low we should get, on

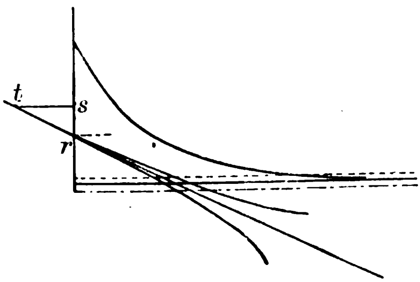
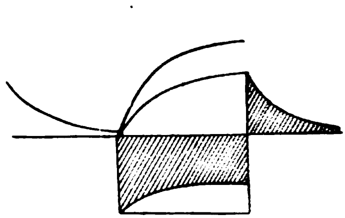


FIG. 18.



CURVE XXVIII.—Shaded Area defines V during charge and discharge.

plotting logarithms, curves either running out to infinity within a finite time or becoming parallel to the zero line (see Fig. 18).

We can get over this difficulty in the following way. We know y measured from the true zero is $k\,\epsilon^{-px}$. Let us write y_0 measuring from false zero as $M + k\,\epsilon^{-px}$, then

$$\frac{d\,(\log_\epsilon y_0)}{d\,x} = \frac{-\,p\,k\,\epsilon^{-px}}{M + k\,\epsilon^{-px}} = -\,p\,\frac{y}{y_0}$$

that is measuring the slope of the logarithmic curve reckoned from the false zero line gives us an inaccurate result in the ratio of y to y_0 at the point in question. It is clear then that the logarithmic curve will become more and more nearly straight as it approaches the vertical axis of y, if therefore it be produced and the slope measured at this point we know the error should not be more than $\frac{y}{y_0}$ at the origin, which in my opinion might easily be kept down to within 1 per cent.

If before drawing the logarithmic curve we multiply our log y values by $\frac{x_1}{t_1}$, then the slope will be such that if we mark off on the vertical axis $r\,s$ to represent R in ohms, $s\,t$ will represent L in secohms.

* $\frac{R}{L}\,t$ is a mere numeric ; the dimensions come out $M^0\,L^0\,T^0$.

Curves XXVIII. and XXIX. represent the way the potential rises at the terminals of a self-induction shunted with a resistance greater than its own when the circuit is ruptured; the connections were made as in Fig. 19, the curves explain themselves.

The strip S_2 being connected across the self-induction as shunt really acts as a voltmeter. When the discharge takes place the same current flows through each strip, the rise of voltage is therefore represented by $Ob—Oa$; Oa representing the voltage at the instant before discharge. Of course, by making *r* large enough the potential across the self-induction might be brought up to any value provided the circuit be ruptured with absolute suddenness, *i.e.*, no spark occur at break, and there be no eddy currents induced anywhere by the circuit. These conditions are, of course, impossible, but it is well known that there is really no absolute limit to the rise of potential on rupturing a circuit possessing self-induction.

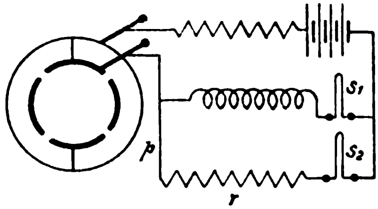
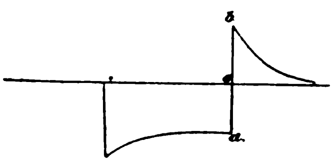
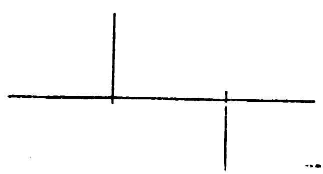


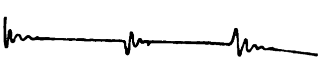
FIG. 19.

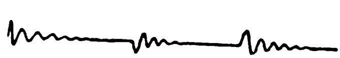
We now come to the oscillatory charge and discharge currents in circuits containing self-inductions and capacities. These experiments were made as indicated in Fig. 16. and are represented in Curves XXX.–XXXVI.



CURVE XXIX.—Taken from Curve XXVIII. $o\,b–o\,a$ represents rise in voltage on opening circuit.


CURVE XXX.


CURVE XXXI.


CURVE XXXII.

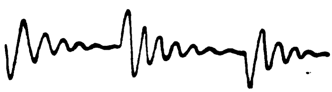
In the first series we start with capacity only; the charge and discharge are so rapid that the oscillograph apparently overshoots the zero line.

The exponential term in this case is $\epsilon^{-\frac{1}{KR}t}$ In my experiments the capacity was $1{\cdot}5 \times 10^{-6}$ farads, and resistance roughly 25 ohms. The maximum self-induction coefficient was approximately ·33 secohm (it was a variable self-induction depending on the current strength), the

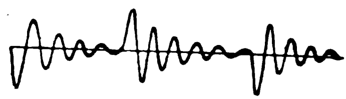
combination therefore had a natural frequency of about 225 cycles per second.

We see then that $\frac{1}{KR} = 2{\cdot}67 \times 10^4$, and $\frac{R}{L} = 75$, that is the process depicted in Curve XXV. as happening in $\frac{1}{30}$th second, occurs in Curve XXX. in $\frac{1}{17600}$th second. Under these circumstances the natural frequency of the oscillograph strips will, of course, come into play.

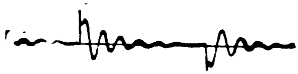
Curves XXXI.–XXXIV. represent the oscillations in the self-same circuit, as the self-induction is gradually increased. It is to be noticed throughout that the resistance in circuit on discharge is always less than that on "make." An examination of Fig. 16 will show that this is the case.



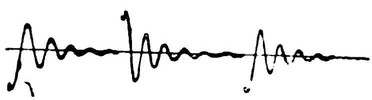
CURVE XXXIII



CURVE XXXIV.



CURVE XXXV.



CURVE XXXVI

Curves XXXV.–XXXVI. were taken with exactly the same apparatus, with the exception of the self-induction. Here a different transformer was used. I reproduce them on account of the irregularities at "make" and discharge. I cannot quite account for this. I certainly had some leakage effects going on in the circuit, but they did not seem able to account for this initial irregularity. There was another abnormality which I noticed on closing the circuit; there was an instantaneous oscillatory curve depicted very much larger than the permanent ones. It was merely instantaneous. This, again, may have been a charge leaking into the condenser in some way, but I had no time to investigate it fully. Perhaps the mathematicians will tell me if some other effect is possible, and, if so, it would be well worth while to try and repeat it, and investigate the matter further.

Curves XXXI.–XXXVI. show distinctly how rises of potential occur on switching cables either on to direct- or alternating-current machines.

The curves themselves are curves of current, but we know that the curve of E.M.F. across the condenser is of the same shape but displaced in phase, the maximum of E.M.F. occurring when the current is zero.

In this case it is easy to see that the maximum voltage across the condenser will reach nearly twice the steady value, thus :—

At the moment of closing the switch the current is zero, therefore the ohmic drop is zero.

The charge in the condenser being zero, v is likewise zero (see Fig. 20). The supply E.M.F. V must therefore be counterbalanced by a back E.M.F. in the self-induction due to the growth of the magnetic flux.

Now the voltage across the self-induction is $(V - v)$, but since $C = K\frac{dv}{dt}$, and at zero time $C = O$, we have at the moment of closing the switch the voltage across the self-induction or $V - v = V$ and $d\frac{(V-v)}{dt} = o$; this means that this voltage starts at its maximum value, viz., V. If we subtract V and reverse, we get the voltage across the condenser or v. The oscillations of v and c are shown in Fig. 21.

We see then at an instant after the start or at the end of the time of one-half oscillation the voltage v has risen up to nearly twice V. The voltage across the cable therefore oscillates about the constant value V, and finally settles down to that steady value. As there are a number of important particular cases where such oscillations arise in general practice, I will here state a few using a minimum of mathematical symbols.

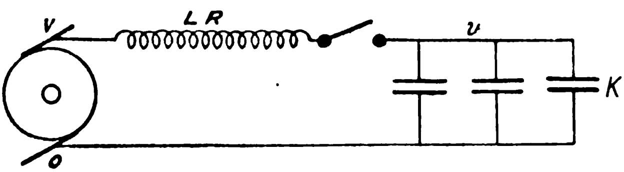


FIG. 20.

The differential equation which holds for case in Fig. 20 is of the familiar form—

$$\frac{d^2 v}{d t^2} + \frac{R}{L}\frac{d v}{d t} + \frac{v}{L K} = \frac{V}{L K} \quad . \; . \; . \; . \; . \; . \; . \; . \; (15)$$

Now, in the cases we are about to consider, V may have a constant value, and the equation applies to the charge portion of curves XXXI.–XXXIV.; V may be zero, as in the case of the discharge portions of the same curves; or V may be a sine function of the time, or

$$V_0 \sin 2\pi n t.$$

In the first case we know the general expression

$$v = V + A\epsilon^{-\frac{R}{2L}t} \sin\left\{\sqrt{\left(\frac{1}{LK} - \frac{R^2}{4L^2}\right)}\, t + \phi\right\} \quad . \; . \; (16)$$

satisfies equation (15).

If, however, $\frac{1}{LK}$ is $\lesseqgtr \frac{R^2}{4L^2}$ the discharge is no longer oscillatory, and we shall not consider these cases.

A and ϕ are constants depending on the particular conditions of the problem which must be fulfilled.

If V is zero, the solution (16) may still be applied.

If $V = V_0 \sin 2\pi n t$, we know that the final state at which the voltage v will arrive will likewise be a sine function. We can write down this final state as

$$v = \frac{V_0 \sin 2\pi n t}{L K \theta^2 + R K \theta + 1} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (17)$$

Where θ* represents the operator $\frac{d}{dt}$; we will express this function as $v = v_0 \sin (2\pi n t + \phi^1)$.

A general solution which will be applicable to the initial as well as the final state of things will therefore be—

$$v = v_0 \sin (2\pi n t + \phi^1) + A\epsilon^{-\frac{R}{2L}t} \sin \left\{ \sqrt{\left(\frac{1}{LK} - \frac{R^2}{4L^2}\right)}\, t + \phi \right) \quad (18)$$

The current, or $K \frac{dv}{dt}$ will in this case be represented by the expression—

$$C = 2\pi n K v_0 \cos (2\pi n t + \phi^1) + \frac{AK}{\sqrt{LK}} \epsilon^{-\frac{R}{2L}t}$$

$$\cos \left\{ \sqrt{\left(\frac{1}{LK} - \frac{R^2}{4L^2}\right)}\, t + \phi + \tan^{-1} \sqrt{\frac{R^2 K}{4L - R^2 K}} \right\} \quad (18a)$$

The first expression representing the final state, and the latter the initial disturbance.

We shall have occasion to make use of this result later.

We will now, however, make a small digression, and briefly examine the nature of the oscillation represented by—

$$v = A'\epsilon^{-at} \sin \beta t \left\{ \begin{array}{l} \text{where } a = \dfrac{R}{2L} \\ \text{and } \beta = \sqrt{\dfrac{1}{LK} - \dfrac{R^2}{4L^2}} \end{array} \right.$$

We will take the case where the voltage across the condenser follows this law.

The coefficient A will, in lieu of a better term, be called the coefficient of the oscillation. v will be zero when $\beta t = n\pi$, or when $t = \frac{n\pi}{\beta}$; n being any integer. The successive zero values, therefore occur after equal intervals of time, viz., $\frac{\pi}{\beta}$.

The maxima will occur when $\frac{dv}{dt} = o$;

but $$\frac{dv}{dt} = - \frac{A}{\sqrt{LK}} \epsilon^{-at} \sin \left(\beta t - \tan^{-1} \frac{\beta}{a}\right).$$

Hence the maxima occur when

$$t = \frac{n\pi + \tan^{-1}\frac{\beta}{a}}{\beta}$$

* See Perry's "Calculus for Engineers."

This shows that the successive maxima occur after equal intervals of time, viz., $\frac{\pi}{\beta}$, but they do not necessarily occur exactly in the middle of the time-interval between the two successive zero values. Since the current through the condenser $= K\frac{d\,v}{d\,t}$, it is clear that the zero values of the current occur simultaneously with the maximum values of the voltage across the condenser.

The maximum values of the current occur when $\frac{d^2 v}{d\,t^2} = o$, or when

$$\frac{A}{L\,K}\epsilon^{-a\,t}\left(\sin\beta\,t - 2\tan^{-1}\frac{\beta}{a}\right) = o$$

i.e., when $t = \dfrac{n\,\pi + 2\tan^{-1}\frac{\beta}{a}}{\beta}$

The current maxima therefore do not necessarily occur simultaneously with the zero values of v.

If, however, $\frac{R^2}{4\,L^2}$ may be neglected in comparison with $\frac{1}{L\,K}$,

$$\tan^{-1}\frac{\beta}{a} = \frac{\pi}{2}$$

and we can represent the current by the expression—

$$\frac{A\,K}{\sqrt{L\,K}}\epsilon^{-a\,t}\cos\beta\,t,$$

in which case the maxima occur half-way between the zero values, and the current maxima occur simultaneously with the zero values of v.

Further, in this case and with the oscillation $A\,\epsilon^{-\frac{R}{2L}t}\sin\beta\,t$ the absolute maximum occurs after time $\frac{\pi}{2\,\beta}$, the value being—

$$A\,\epsilon^{-\frac{\pi}{4}\sqrt{\frac{R^2K}{L}}},$$

and in the case of the oscillation $A\,\epsilon^{-\frac{R}{2L}}\cos\beta\,t$, the absolute maximum will be equal to the coefficient of the oscillation, viz., A, *i.e.*, the oscillation starts at its absolute maximum.*

* The oscillation represented by $v = A\epsilon^{-a\,t}\cos\left(\beta\,t - \tan\frac{a}{\beta}\right)$ has zero slope $\left(\text{or } \frac{d\,v}{d\,t} = o\right)$ when $t = o$. This is the true form of the oscillation which starts at a maximum value, viz., $A\frac{\beta}{\sqrt{a^2+\beta^2}}$. Where, however, $\frac{R^2}{4\,L^2}$ may be neglected $\tan^{-1}\frac{a}{\beta} = o$, and the maximum or initial value is A.

In the cases we shall consider here $\frac{R^2}{4L^2}$ is negligible with regard to $\frac{1}{LK}$, so that we may apply the above simplifications, and write as the frequency of oscillation—

$$\frac{1}{2\pi}\sqrt{\frac{1}{LK}}$$

There are two rules which it is of importance to keep in mind on account of their bearing on the voltage and current rises in alternating-current circuits when oscillations are started. They are as follows:—

(1) If in a circuit consisting of a capacity and a self-induction a voltage oscillation be started of which the initial maximum value is v_0, the coefficient of the current oscillation will be—

$$\frac{C_0\sqrt{\frac{1}{LK}}}{2\pi n}$$

where C_0 is the maximum value of the condenser current after the steady state has been reached if the voltage $v_0 \sin 2\pi n t$ is applied at its terminals.

(2) If a current oscillation be started of which the initial maximum value is C_0, the coefficient of the corresponding voltage oscillation will be—

$$\frac{v_0\sqrt{\frac{1}{LK}}}{2\pi n}$$

where v_0 is the maximum value of the voltage wave which must be applied to the terminals of the self-induction in order that the current, after the steady state has been reached, may be of the shape $C_0 \sin 2\pi n t$.

$$\frac{\sqrt{\frac{1}{LK}}}{2\pi n}$$

represents, of course, the ratio of the frequency of the oscillation to the frequency of the supply circuit. These rules are the obvious outcome of what has preceded.

We will now return to the treatment of the case where, say, a cable is switched on to a D.C. generator which possesses self-induction. v is represented by equation (16).

At time $t = o$ we have to satisfy the conditions $v = o$ and $\frac{dv}{dt} = o$ or $C = o$.

The first of these conditions results in the equation $V = -A \sin \phi$, and the second shows us that at time o the oscillation starts at maximum or crest.

The frequency of oscillation will be—

$$\sqrt{\frac{1}{LK} - \frac{R^2}{4L^2}};$$

the time occupied by a half oscillation will be—

$$t = \frac{\pi}{\sqrt{\frac{1}{LK} - \frac{R^2}{4L^2}}}$$

$$\therefore \text{ at time } t = \frac{\pi}{\sqrt{\frac{1}{LK} - \frac{R^2}{4L^2}}}$$

$$v = V + A\epsilon^{-\frac{R}{2L} \cdot \frac{\pi}{\sqrt{\frac{1}{LK} - \frac{R^2}{4L^2}}}} \sin(\phi + \pi)$$

$$= V\left(1 + \epsilon^{-\frac{\pi}{\sqrt{\frac{4L}{R^2K} - 1}}}\right) \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; (19)$$

and this will be the maximum value to which the E.M.F. across the cable can rise.

At the limit $\frac{4L}{R^2 K} = 1$, which is the limit at which the current ceases to be oscillatory, $v = V$ and there is no rise of voltage.

We cannot take a negative value for the $\surd$ term in equation (19), for taking the negative value of the square root gives a result for something that was happening before we began to count time. It has no meaning except in the case of an oscillation having been started, and the zero of time being taken at some period subsequently.

We can therefore dismiss this case. The value of the exponential in (19) must therefore be between 1 and 0. We have discussed the latter condition. The former is attained when $\frac{1}{R^2 K} = \infty$. Therefore when R or K is very small, or when L is very large, v will rise to a maximum of practically twice V.

It is interesting to think of the case where a voltage V is suddenly applied to one end of a coil of large self-induction and low resistance, the other end being free. The interruption in the circuit is equivalent to a very minute capacity. An extremely rapid oscillation will then be set up through the coil, and the potential at the free end will oscillate about a mean V with an extremely high frequency, the oscillation continuing for an appreciable time. We are now getting into the range of the wireless telegraphist. In the case of a cable being switched on to an alternator we may apply the self-same result if the circuit be closed at the maximum of the E.M.F. wave, and this be sufficiently flat or the oscillation sufficiently rapid for us to assume that there is no appreciable diminution of the E.M.F. during the time of one-half oscillation. In this case we may say the maximum voltage will be nearly twice V, and under other conditions less.

If the cable be already charged and have a potential difference at its terminals of $-V$, and be switched on to a circuit of P.D. $+V$, the maximum to which it can be subjected will be nearly 3 V.

It will be seen at once in the case of a steady voltage V, and it can be shown to be equally true in any other case, that provided R is small in comparison with $2\pi n L$ in Fig. 20, the voltage across L due to the

oscillation is at every instant equal and opposite to v, hence we have the same condition as that for resonance during the steady state, viz., that a current flowing through a self-induction in series with a capacity produced a P.D. across the former equal to that across the latter, but opposed in direction. In these initial stages we are therefore also dealing with resonance effects, the difference between that, where we have a steady state of resonance, we have to adjust L and K so that $\frac{1}{2\pi} \cdot \frac{1}{\sqrt{LK}}$ corresponds to the frequency of the supply circuit. During the unsteady state we have resonance with any values of L and K, for given an initial pulse of E.M.F. or current, the frequency of oscillation (n_1) will be self-adjusting so that still $2\pi n_1 = \frac{1}{\sqrt{LK}}$. If the circuit in Fig. 20 be closed when the E.M.F. is zero, the steady state is not instantly reached, for this would imply that the current into the cable was very nearly at its maximum value, but we know that it will be zero. We have therefore to consider the expotential term in equation (18).

The conditions we have to satisfy are, at time

$$t = 0 \qquad V = 0$$
$$v = 0 \qquad \text{and } \frac{dv}{dt} = 0$$
$$C = 0$$

The first condition is already satisfied where $V = V_0 \sin 2\pi n t$.
The second involves $v_0 \sin \phi^1 + A \sin \phi = 0$ . . . . (20)
The third involves—

$$2\pi n K v_0 \cos \phi^1 + \frac{AK}{\sqrt{LK}} \cos \left\{ \phi + \tan^{-1}\left(\frac{\alpha}{\beta}\right) \right\} = 0 \quad . (21)$$

These conditions merely state that the initial value of the voltage and current oscillation are equal and opposite to the values of voltage and current which exist after the steady state has been reached at the moment of the E.M.F. wave when V passes through the zero.

We can of course solve equations (20) and (21), and obtain A and ϕ in terms of v_0 and ϕ^1 which again are determinable from equation (17).

But in the case under consideration we can cut this short in the following manner :—We know that the P.D. across the self-induction (which is the self-induction of the generator) is practically directly in line with V, in other words $\phi^1 = 0$, and therefore also $\phi = 0$. There is still another condition which must be true at time $t = 0$. We know that at every instant the P.D. across the self-induction $= V - v$, but $(V - v)$ may be expressed as :—

$$L \frac{dC}{dt} + RC,$$

at time $t = 0$ this is also zero, and therefore if R is small in comparison with L (which is the case with every alternator) we may say $\frac{dC}{dt} = 0$ at zero time.

This last condition shows us that at the moment of starting, the

current oscillation has its *maximum* value, which is equal and opposite to $2\pi n K v_0$. We may therefore say at once that the coefficient of the oscillatory voltage is—

$$v_0 \frac{2\pi n}{\sqrt{\frac{1}{LK}}}$$

This will be a very small oscillation which starts when v_0 is zero; the rise of voltage across the cable will therefore be very small if switched in at the moment of zero E.M.F., but there will be a current oscillation of which the initial value equals the maximum value after the steady state has been reached.

I do not propose to lengthen out this inquiry by going into other more complicated cases, such as switching on cables with transformers connected across the ends, or switching on circuits to generators already loaded on other circuits, since in no case are greater rises

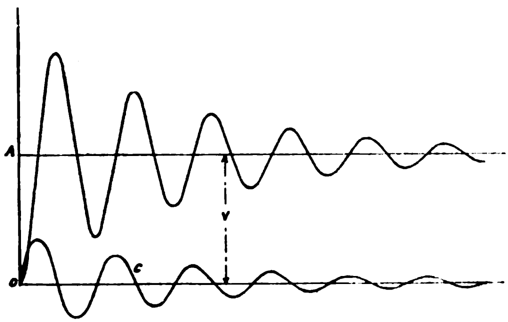


FIG. 21.

of potential called into existence by initial disturbances than those we have already considered.

I will therefore take up the special case of switching off a cable circuit already loaded with a highly inductive circuit, such as lightly loaded transformers, or worse still, a circuit opening on the high-tension side, the low-tension circuit being loaded on an inductive load.

Two limiting cases are those of special interest—(1) When the circuit is broken at the moment the current is passing through zero; (2) when the circuit is broken at the instant the current is at its maximum.

Dealing first with the case of a bank of transformers, the secondary of which is on open circuit.

Let the maximum of the charging current of the cable be C_K and of the transformers C_L, then we have the relations—

$$C_K = 4\pi^2 n^2 L K C_L \text{ and } 2\pi n L C_L = v_0$$

If the circuit be opened at the moment the current C_K and C_L are

zero, the voltage being v_0 or the maximum of the steady state, it is clear that there will be excited a voltage oscillation starting with a maximum value of v_0. The coefficient of the current oscillation will be $\sqrt{\frac{K}{L}} v_0$, that is to say, the coefficient is to C_K in the ratio of the frequency of oscillation to n; and to C_L in the inverse ratio. There will, however, be no rise of voltage.

If the circuit be opened when C_L and C_K are at their maximum values, or when the voltage is zero, a current oscillation will be excited starting with the maximum value C_L.

The coefficient of the voltage oscillation will then be $\sqrt{\frac{L}{K}} C_L$, that is to say, the coefficient is to v_0 in the ratio of the frequency of oscillation to the frequency n. This will, of course, usually result in a considerable rise of potential. If the secondary, however, be not an open circuit, it may act more or less as a short-circuited turn and either damp down the violence of the oscillation if the secondary circuit be non-inductive, or increase the violence of the same if the load be very inductive. In any case the effect of the

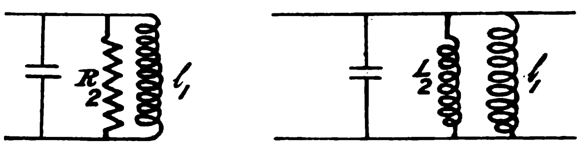


FIG. 22.

secondary may be represented by a shunt circuit in the primary, thus in Fig. 22, l_1 represents a choke coil having the same self-induction coefficient (l_1) as the primary circuit of the transformer on no load. R_2 L_2 represent the resistance or self-induction, as the case may be, which, when connected in parallel with l_1 will behave, as far as the supply circuit is concerned, as does the transformer on load. If the transformer supplied motors, it would be necessary to include in the shunt circuit a back E.M.F. Taking the worst case, where the secondary circuit is loaded inductively at the moment of interrupting; it is clear that during the oscillation that follows the total energy of the system will be at one instant stored electro-magnetically in the magnetic field interlinked with the circuit, at another electro-statically in the capacity.

The total energy at the moment of interrupting is

$$\frac{1}{2} K v^2 + \frac{1}{2} l_1 \left(C_1 - \frac{\sigma_2}{\sigma_1} C_2\right)^2 + \frac{1}{2} L C_2^2,$$

the first term representing the total energy stored in the capacity in watt-seconds at the moment of interrupting, K being the capacity and v the voltage at the terminals at the moment in question; the second term being the watt-seconds stored in the transformer due to its

magnetic state, C_1 C_2 being the primary and secondary current at the moment of interrupting, and σ_1 σ_2 the number of turns of primary and secondary respectively; while the last term represents the energy stored electro-magnetically in the secondary external circuit; L being coefficient of self-induction of this external circuit.

The maximum value of the voltage oscillation will be slightly less than V, where

$$V = \sqrt{v'^2 + \frac{l_1}{K}\left(C_1 - \frac{\sigma_2}{\sigma_1} C_2\right)^2 + \frac{L}{K} C_2^2}.$$

This, of course, is readily calculable; it will represent a very considerable and usually a highly destructive rise of potential.

As a last example of the kind, we will consider the oscillation in a circuit consisting of a capacity and self-induction, where at the moment of the interruption the voltage across the capacity is $-v_1$, and the current flowing through the self-induction is C_1.

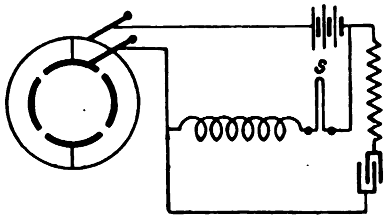


FIG. 23.

We can consider the voltage oscillation as the resultant of two components, the first given by the conditions when $t = o$, $v = o$, $C = C_1$, the second given by the conditions when $t = o$, $v = -v_1$, $C = o$. It is clear that the sum of these oscillations will satisfy the fundamental equation, and the initial conditions, viz., when $t = o$, $v = -v_1$, $C = C_1$.

We have, however, already considered both components separately, and can write down the oscillations forthwith in their approximate forms, as :—

$$v = -v_1 \epsilon^{-\frac{R}{2L}t} \cos\left(\sqrt{\frac{1}{LK}}\right) t + C_1 \sqrt{\frac{L}{K}}\, \epsilon^{-\frac{R}{2L}t} \sin\left(\sqrt{\frac{1}{LK}}\right) t$$

$$C = v_1 \sqrt{\frac{K}{L}}\, \epsilon^{-\frac{R}{2L}t} \sin\left(\sqrt{\frac{1}{LK}}\right) t + C_1 \epsilon^{-\frac{R}{2L}t} \cos\left(\sqrt{\frac{1}{LK}}\right) t,$$

or—

$$v = \sqrt{v_1^2 + C_1^2 \frac{L}{K}}\, \epsilon^{-\frac{R}{2L}t} \sin\left\{\left(\sqrt{\frac{1}{LK}}\right) t - \tan^{-1} \frac{v_1}{C_1 \sqrt{\frac{L}{K}}}\right\}$$

$$C = \sqrt{v_1^2 \frac{K}{L} + C_1^2}\, \epsilon^{-\frac{R}{2L}t} \cos\left\{\left(\sqrt{\frac{1}{LK}}\right) t - \tan^{-1} \frac{v_1}{C_1 \sqrt{\frac{L}{K}}}\right\}$$

I could have obtained these results by means of the oscillograph had I thought my capacities would have stood the severe strain.

The connections would have been as in Fig. 23. The current curve

through S would then be of the nature shown in Fig. 24. If we make the resistance in the battery circuit one-half that in the condenser circuit, we have the exponential terms during both charge and discharge operations the same; in other words, the curve representing the oscillation will be found to just fit into the cone formed by taking two of the curves A B C, representing the charge period. This is shown dotted in the diagram.

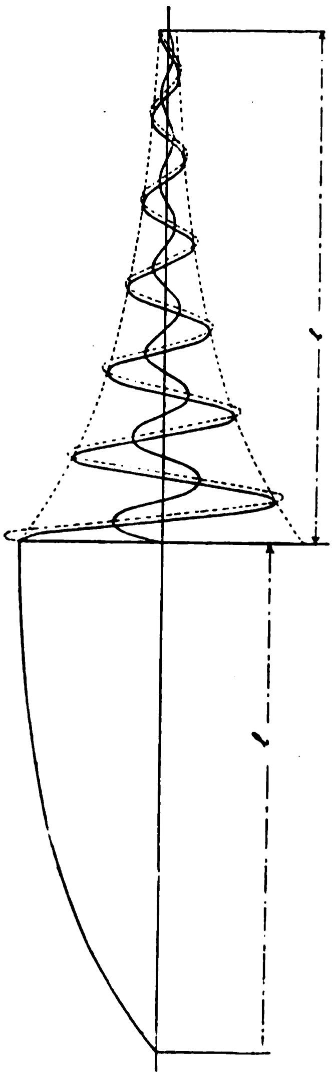


FIG. 24.

A few words with regard to the frequency of oscillation of which we have been speaking.

A 5,000-volt câble of such length as to give 1 microfarad capacity connected to a transformer of which the magnetising current was 1 ampere at 50 $\sim$, or with an L of 15·9 secohms, would resonate with a frequency $\frac{1}{2\pi}\sqrt{\frac{10^6}{15{\cdot}9}}$ or 40 cycles per second. A generator on the other hand which would give a short-circuit current of 200 amperes, or with an L of $\frac{15{\cdot}9}{200}$ secohms would produce an oscillation of frequency of $40 \times \sqrt{200} = 560$. In large systems the oscillations produced on switching on cables to their generator will usually be of a much higher order than those produced in the system on switching off.

PART III.

We have up to the present assumed that, provided the 3-phase system be symmetrical, the capacity effect of the cables may be exactly reproduced by substituting in place of the cables conductors without capacity, but with a single combination of capacities

connected between them and earth, as represented in Fig. 14. We know, however, that this is not strictly true; a 3-core cable really can only be represented by a distributed capacity, as in Fig. 25, where A B C represent the 3 cores, and the dotted line an imaginary earthed conductor of zero resistance. Now, if in this case an E.M.F. be suddenly applied at one end of the cable, the other being open-circuited, the whole cable does not become instantly charged; *i.e.*, the current at the point p_1 in core A will have a different value from that at point p_2 at every instant. Further, the potential at p_1 above earth will not be the same as that at p_2, and the quantity of electricity charging the cable per cm. length at p_1 will be different from that at p_2.

On the other hand a definite and appreciable time will be necessary for the charge to be felt all along the cable.

We have, in fact, the same sort of problem as that of sending signals through the Atlantic cable, where, if a pulse of E.M.F. or current be injected into the cable at one end, an appreciable time is required before the pulse is manifested at the far end.

What goes on may be briefly stated to be as follows :—

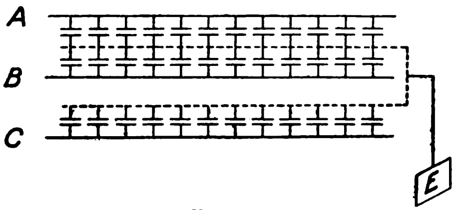


FIG. 25.

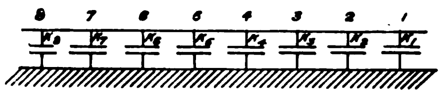


FIG. 26.

If at any instant the potential at 1 (Fig. 26) is zero, and current is flowing from 2 to 1, the potential at 2 will be positive, which means that the capacity k_2 must have a definite charge while that of k_1 is zero.

Again, if current is flowing from 5 to 4 to 3 to 2, the potential at 5 will be higher than 4, of 4 than 3, of 3 than 2; hence the charge in k_5 is greater than that in k_4; of k_4 than k_3; of k_3 than k_2. Now every capacity takes an appreciable time to charge, and, therefore, there will be a time-growth of charge along the cable, k_1 arriving at its full charge last.

Now let us assume that by the time k_1 has received a definite charge the potential at the sending end has been gradually reduced to zero; the charge in the initial capacity will then be zero, and in the final capacity k_1 a maximum. We have then the exact reverse of the initial state when the charge in k_8 was a maximum and in k_1 zero. There will now be a return current tending to equilibriate the potential along the conductor. This return or reflected wave will require a definite time interval to reach the sending end, and if the applied E.M.F. at the sending end is periodic, and the returning waves synchronise with the applied periodic E.M.F., a state of resonance will be set up. This might reach dangerous proportions,

a small E.M.F. at the sending end involving an extremely high P.D. at the far end.

I have worked out this case for a 3-core cable, with an impressed E.M.F. at one end, consisting of a fundamental of 25 cycles and a 13th harmonic; but find that the length of cable required before a dangerous state of resonance is set up is far beyond anything at present in use in this country for power transmission purposes. I do not propose to give the full mathematical details of this problem as they may be found elsewhere.

As, however, this particular case of the general problem is interesting to electrical engineers, I propose to apply here the solution of the same to a practical case.

We will confine our attention to a 3-core lead-sheathed high-tension cable; area per core = ·2 □″

Let ρ = resistance of 1 core per mile = ·22 ohm.

Let κ = equivalent capacity per leg per mile (see Fig. 14) = $\cdot 5 \times 10^{-6}$ farads.

Let λ* = coefficient of self-induction per core per mile (*i.e.*, λ is a coefficient such that volts drop in *each* core per mile $= \rho\, c + \lambda \frac{d\,c}{d\,t}\Big)$.

Let c be the current at any point and at any time, flowing axially along the conductor under consideration.

Let v be the potential above earth at a similar point.

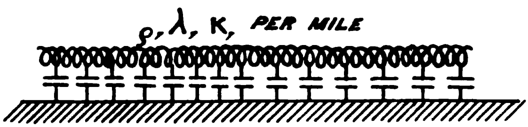


FIG. 27.

We need only consider one core, and may think of it as consisting of a conductor as represented in Fig. 27.

The cable is on open circuit at the far end; at the near end a sine wave of E.M.F. is applied.

The fundamental differential equations of the problem are:—

$$\frac{d^2 v}{d\,x^2} = \rho\,\kappa\,\frac{d\,v}{d\,t} + \lambda\,\kappa\,\frac{d^2 v}{d\,t^2} \quad \ldots \ldots \quad (22)$$

$$\frac{d^2 c}{d\,x^2} = \rho\,\kappa\,\frac{d\,c}{d\,t} + \lambda\,\kappa\,\frac{d^2 c}{d\,t^2} \quad \ldots \ldots \quad (23)$$

$$\frac{d\,c}{d\,x} = -\,\kappa\,\frac{d\,v}{d\,t} \quad \ldots \ldots \quad (24)$$

* I here represent resistance, coefficient of self-induction, and capacity per unit length, by Greek letters, as these quantities are of different dimensions from the R L K previously employed; we saw that $\sqrt{\frac{1}{L\,K}}$ was of the dimensions of a frequency or $\frac{1}{T}$, we soon shall see that $\sqrt{\frac{1}{\lambda\,\kappa}}$ represents a velocity or $\frac{\text{length}}{T}$. It is of importance, in order to avoid a confusion of ideas, to keep this point well in mind.

A solution for v is—

$$v = V_0 \epsilon^{ax} \sin (2 \pi n t + a x),$$

and for current—

$$c = C_0 \epsilon^{ax} \sin (2 \pi n t + a x + \psi).$$

These solutions would apply to the case of a cable infinitely long; we have, however, to satisfy the terminal conditions—

$$\text{when } x = o, v = V_0 \sin 2 \pi n t,$$
$$\text{when } x = l, c = o,$$

l being the length of the cable in miles.

The particular solutions which satisfy these terminal conditions are:—

$$v = V_1 \epsilon^{-ax} \sin (2 \pi n t - a x + \phi) + V_1 \epsilon^{-a(2l-x)} \sin (2 \pi n t - a (2 l - x) + \phi)$$

$$c = \frac{2 \pi n \kappa V_1}{\sqrt{a_1^2 + a_1^2}} \begin{Bmatrix} \epsilon^{-ax} \sin (2 \pi n t - a x + \phi + \theta) - \\ \epsilon^{-a(2l-x)} \sin (2 \pi n t - a (2 l - x) + \phi + \theta) \end{Bmatrix}$$

$$\text{where } a = \sqrt{\pi n \kappa (I - 2 \pi n \lambda)}$$

$$a = \sqrt{\pi n \kappa (I + 2 \pi n \lambda)}$$

$$I = \sqrt{\rho^2 + 4 \pi^2 n^2 \lambda^2}$$

$$V_1 = \frac{V_0}{\sqrt{1 + \epsilon^{4al} + 2 \epsilon^{-2al} \cos 2 a l}}$$

$$\tan \theta = \frac{a}{a}$$

$$\tan \phi = \frac{\epsilon^{-2al} \sin 2 a l}{1 + \epsilon^{-2al} \cos 2 a l}$$

An examination of the form of the solution of v and c shows that each consists of an original plus a reflected wave. If the cable had a length of $2 l$, then the first term gives the value of the original wave at, say, the point p_1; the second the value of the same wave at point p_2 (Fig. 28), and the solution tells us that in the case of the cable of length l, the actual value of the wave at p^1 is in the case of the E.M.F. the sum of the value at p_1 and p_2 at every instant; in the case of the current the actual wave at p_1 is the difference between the values at p^1 and p_2.

It will be noticed that the differential equations (22), (23), (24), which obtain for the case in question involve three conditions:—

(1st) If we consider any particular short portion of a given cable such as $a\ b$, the quantity of electricity entering this portion axially at a in a given time is equal to the quantity leaving axially at b, plus the accumulation of electricity at the side walls bounding the portion $a\ b$.

(2nd) The accumulation of electricity as above is equal to the pressure obtaining at the portion of the cable a b, multiplied by a constant depending on the nature of the containing walls, and not on the conductor. If this constant is zero there can be no accumulation, and the quantity entering *a* equals the quantity leaving at *b*. The above, which merely state the electrical conditions, are obviously those for an incompressible fluid flowing through a pipe with elastic side-walls. For if the side-walls be rigid there can be no accumulation in any portion of the tube; if elastic, the quantity entering any cross-section such as *a* equals that leaving another cross-section *b*, plus the accumulation in the portion *a b*, this accumulation taking place in virtue of the elasticity of the side-walls, and *not* being due to any compressibility of the fluid itself.

The 3rd condition is that the potential gradient at any moment and at any cross-section is the sum of two factors—the first proportional to the quantity per second passing the cross-section at that

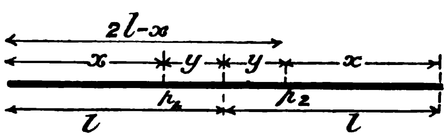


FIG. 28.

moment, and second proportional to the quantity per second per second or the acceleration.*

This last condition would similarly hold for a fluid possessing inertia, and being retarded in its passage by true fluid friction (*i.e.*, loss of head ∝ velocity). Now all these three conditions will very nearly obtain in the case of water flowing through an indiarubber tube. This is a most useful analogy to fix our ideas of what goes on in a cable. (It will be noticed that the analogy of an organ pipe which has been proposed is quite inaccurate, for in this case we should be dealing with a compressible fluid in a pipe with rigid containing walls.) I should like to see a model made consisting of a suitable elastic tube with a blind end in which was included a small reciprocating pump. In this way we should be able to follow the propagation and reflection of the waves, also the propagation of individual wave fronts, a most important point which we shall touch on later. It is to be observed that the hydrostatic pressure at any portion of the tube corresponds to the electric potential at any portion of the cable, while the velocity of the fluid corresponds to the current strength.

We shall obtain maximum resonance when $a\,l = \frac{\pi}{2}$; or when $l = \frac{\pi}{2a}$.

* The equation representing this in the electrical case will be

$$\frac{dv}{dx} = \rho c + \lambda \frac{dc}{dt}.$$

In this case the E.M.F. at the sending end will be of effective value V_0; and at the receiving end—

$$\frac{2\,\epsilon^{-\frac{\pi}{2}\tan\theta}}{\sqrt{1+\epsilon^{-2\pi\tan\theta}-2\,\epsilon^{-\pi\tan\theta}}}\cdot V_0$$

$$\text{or}\quad \frac{2\,\epsilon^{-\frac{\pi}{2}\tan\theta}}{1-\epsilon^{-\pi\tan\theta}}\cdot V_0$$

We will apply these conclusions to the case of a 50 cycle circuit, containing a 13th harmonic or where $n = 650 \sim$ λ can be calculated from the formula—

$$* \lambda = \left(\log_\epsilon \frac{b}{a} + \frac{1}{2}\right) 10^{-4} \times 3{\cdot}22$$

where b = distance between cores, a = radius of each core.

Let us take a = ·275 □″ b = ·8″, then λ per core per mile = ·000502 secohm.

If we say roughly that at this frequency $2\pi n\lambda = 10\rho$

$$\therefore \frac{a}{\alpha} = \sqrt{\frac{1-2\pi n\lambda}{1+2\pi n\lambda}} = \tfrac{1}{20}\text{ approx.}$$

$$\text{and}\quad \frac{2\,\epsilon^{-\frac{\pi}{2}\tan\theta}}{1-\epsilon^{-\pi\tan\theta}} = 12{\cdot}7.$$

It follows then that 13th harmonic will be magnified 12·7 times at the end of the cable.

Putting in the above values of ρ, κ, and λ in the expression $\frac{\pi}{2a}$ we have $l = 23{\cdot}5$ miles.

It appears, therefore, it is quite within the region of possibility for this class of resonance to occur on a system of moderate frequency, supplying very long cables, and with slotted armatures containing two or more slots per pole per phase. This case, though of importance

* This formula gives half the value of the self-induction of a circuit made up of two parallel wires. In the 3-phase case the current in core 1 is at every instant equal to the sum of the currents in 2 and 3. Now, the effects of the currents in 2 and 3 on 1 will be independent of their relative positions, provided their radial distance from 1 is not changed—we can therefore consider them coincident, and calculate the effect on 1 as in the single-phase case. We may consequently take the self-induction of a loop with the same current per line as in 1, halve it and consider this the E.M.F. of self-induction acting in each of the line wires 1, 2, and 3 at right angles to the currents in those line wires. It is interesting to note that this formula will give the same result per line wire as if we calculate the self-induction of the inner of a concentric cable, the inner being of the same diameter as each core in the 3-phase cable, and the radius of the outer being the same as the distance between centres of the three individual cores, provided this dimension is large in comparison with the radial thickness of the outer conductor.

in electrical engineering, and deserving of careful consideration, need not necessarily cause uneasiness.

The value of the P.D. due to the harmonic at any intermediate point of the cable will lie between V_0 and $12{\cdot}7\ V_0$.

It is well known that the capacity effect of these long cables can be imitated almost perfectly by connecting up a number of smaller capacities with wire containing resistance and self-induction, and I suggest it would be a subject of vast interest if some one would investigate this matter experimentally rather than mathematically.

It is to be noted that since $\frac{2\pi}{a}$ is the wave length of the space wave in the cable, the velocity of propagation is $\frac{2\pi n}{a}$; when dealing with such high frequencies that we can afford to neglect ρ, $a = 2\pi n\sqrt{\lambda\kappa}$, and the velocity of propagation becomes $\sqrt{\frac{1}{\lambda\kappa}}$ miles per second.

If $\lambda = 5 \times 10^{-4}$, and $\kappa = {\cdot}5 \times 10^{-6}$; $\sqrt{\frac{1}{\lambda\kappa}} = 63{,}200$ miles per second, or approximately $\frac{1}{3}$ the velocity of light.

There is still an important aspect of the subject of High Potential Rises in circuits containing distributed capacity, self-induction, and resistance (and every circuit does to a greater or less extent) which I have not touched upon. I refer to the initial disturbances in such circuits when the potential at any one point is suddenly altered. The subject is a very difficult one to treat mathematically in at all a general manner; it must therefore be experimentally investigated. I doubt even if the oscillograph will be of much aid here on account of the extreme rapidity with which the phenomena take place.

A most interesting paper on the subject, entitled "Static Strains in High-Tension Circuits and the Protection of Apparatus," was read by Mr. Percy H. Thomas before the American Institute of Electrical Engineers, 14th February, 1902, which is well worth study by all who are interested in the subject. I am under the impression (I hope I am mistaken) that the Proceedings of the American Institute of Electrical Engineers are not read on this side with the attention they deserve, and I will ask pardon for briefly explaining here the nature of the so-called "Static Strains" of which the above-referred-to paper treats.

In Fig. 29, S represents a source of high potential (V). A B, a circuit or line of any nature at zero potential.

At the instant before closing the switch, the potential is represented by the full black line in Fig. 30. Now on closing the switch the line A B cannot, as we have seen, be instantly raised to the potential V; in fact, at the moment of closing, the potential (assuming no spark occurs) all along the circuit would likewise be represented by the full line in Fig. 30. Instantly, however, the charge in the portion of the system S T begins to distribute itself over the whole system from S to B, the first effect being a tendency for the electro-static charges in the neighbourhood of the switch to equalise themselves, resulting in a moderation of the steepness of the potential line, as shown dotted in Fig. 30.

This potential "front" will then travel along the system to B, becoming modified as it proceeds, depending on the constants of the line and circuit. The question is, what is the potential gradient at all parts of the circuit as this potential "front" reaches them? It is a question of vast moment. Every one who has worked much with high-tension motors and transformers will have experienced difficulty owing to the short-circuiting of turns and layers in a most curious way. I have seen the winding stripped off high-tension motors, the insulation of which

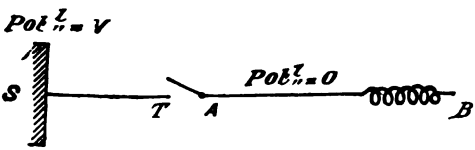


FIG. 29.

was punctured with innumerable pinholes. The normal voltage between turns is a perfectly definite quantity, and accounts in no way for the puncturing. But it is clear that if a potential front with a steep potential gradient traverses the winding, the potential difference between neighbouring windings or layers may be very excessive in comparison with that after the normal steady state has been reached. For example, if the distance *a* in Fig. 30 represents the length of two layers, it would be possible to have momentarily the full potential of the circuit across these layers.

On switching a high-tension motor on to a circuit, both poles cannot be closed simultaneously. On closing the first pole we have the state of things already discussed and represented in Fig. 30. The potential front on reaching the dead end of the circuit is reflected back, there

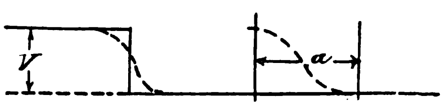


FIG. 30.

occurs, one may almost say, a "splash" of potential, possibly analogous to the splash caused by a sea wave on reaching a boundary wall, and similar to the reflected waves we have already discussed.

The same thing will occur on closing the second pole of the circuit, only in this case the height of the potential front will be twice what it was in the preceding case.

It is, of course, difficult to say whether the strain on the insulation is greater in this case than in the preceding; in general, we may say that if the front extends over a distance of more than two layers of the winding, the strain will be determined by the potential gradient.

These potential fronts may be created at any point of the circuit by suddenly altering the potential at that point, *e.g.*, by short-circuiting grounding, and the like,

This is a subject that will amply repay any one who will undertake a careful research.

In conclusion I should like to state how very powerful a weapon in experimental research Mr. Duddell's oscillograph should prove. There are a vast number of investigations, of which the above are but unhappy samples, which would amply repay any experimenter to carry out. It is only given to mathematicians to see clearly with the mind's eye the full physical interpretations of their symbols; to ordinary engineers, such as myself, who make no pretensions to wielding the mathematical weapons, an optical investigation of such phenomena brings home in a clearer way than pages of mathematics what is really going on. I would suggest that the study of the effect of an arc on opening a high-tension circuit, what goes on in sparks, in so-called liquid capacities such as are used for starting single-phase motors, determining the hysteresis loops of transformer circuits from the load current and voltage curves, and a number of other equally interesting and instructive series of experiments which suggest themselves at once, would form the ground-work for most delightful papers.

These subjects are, moreover, of the greatest commercial importance. Take, for example, the breaking of a high-tension cable circuit in air or in oil, and trace out the rises of potential in the two cases. At first sight one would think the air-break would be best; it is not so, but quite the reverse. What effect has the air arc then on the circuit?

I wish now to acknowledge the very considerable help my former assistant, Mr. S. Blackley, has rendered me in connection with the oscillograms here reproduced. It has meant many a night till 2 or 3 a.m., when after a hard day's work he has given up his spare time and devoted himself to the work with the spirit of an enthusiast. I wish also to express my indebtedness to Dr. Magnus Maclean for the help he has given me in the preparation of this paper.

Professor Magnus Maclean.

Professor MAGNUS MACLEAN wished to compliment Mr. Field on the excellence of his paper submitted, both from an experimental and mathematical point of view. It was a paper with which he was more or less familiar, as Mr. Field was kind enough to show him many of the experiments some time ago, and the theories put forward and the inferences deduced were mutually discussed on several occasions. There were many points in the paper to which he would like to refer, but, as the evening was far advanced, he would confine himself to the investigation which Mr. Field gave to prove that the 11th and 13th harmonics are the most important.* The way in which he showed that an 11th and a 13th could be inferred from the 12 ripples observed in the direct-current voltage was most ingenious, original, and, he thought, correct.

But he did not think that Mr. Field was justified in stating as he did

* It would be more in accordance with ordinary notation and nomenclature to call the term containing a frequency eleven times the fundamental frequency the 10th harmonic, and to call the term containing a frequency thirteen times the fundamental frequency the 12th harmonic. Thus with frequencies 1, 2, 3, 4, . . etc., 2 is the first harmonic, 3 the second harmonic, . . . etc.

Professor Magnus Maclean.

that these harmonics are the most important. As a matter of fact, the mathematical equation from which he deduced this result was an assumed equation: and if one assumed a corresponding equation like $a\,(1 - \cos 6\,k\,t)$, it would follow by the same reasoning and the same nomenclature that the 5th and the 7th frequencies would be the most important. To find by the usual analysis whether lower harmonics were present or not, Professor Maclean got Mr. Blackley to magnify four of the curves by means of a pantagraph. These magnified curves were not very accurate, especially at the ripples, which were much sharper than they should be. This was due, as Mr. Blackley explained to him, to a sticking of the pantagraph. However, he thought they were accurate enough to enable him to find if there were terms containing 3 or 5 times the fundamental frequency. The enlarged curves were XV, XVII, XX, and another not given in the paper, but similar to XXI. He would call it XXI. He only had time to try the last three mentioned curves, and these only for frequencies 3, 5, and 11 times the fundamental. As terms containing even multiples of the fundamental frequency cannot appear in these curves, the general equation is :—

$$f(\mathrm{E}) = \mathrm{E}_1 \sin p\,t + \mathrm{E}_3 \sin (3\,p\,t + \theta_3) + \mathrm{E}_5 \sin (5\,p\,t + \theta_5) + \ldots$$
$$\ldots + \mathrm{E}_{11} \sin (11\,p\,t + \theta_{11}) + \mathrm{E}_{13} \sin (13\,p\,t + \theta_{13}) + \ldots$$

The process of finding E_1 E_3 E_5 . . . etc. is well known. It simply consists for finding E_3 in dividing the whole curve into three equal parts, superimposing these three parts and finding a third of the resultant ordinates at each point of the abscissæ. If this is a sine curve, its maximum ordinate is E_3. Again, to find E_5, divide the whole curve into five equal parts; superimpose these parts and find a fifth of the algebraic sum of the ordinates at each point of the abscissæ. If this curve is a sine curve its maximum ordinate is E_5. The others, E_7 E_9 . . . etc., can be similarly dealt with.

Due to a fault in the oscillogram, as mentioned in the paper by Mr. Field, the distance 0 to π is not equal to the distance π to 2π. Hence, when looking for frequencies 3 and 5, he divided 0 to π into 30 equal parts, and also π to 2π into 30 equal parts. This gave him twenty readings for the curve containing frequency 3, and twelve readings for the curve containing frequency 5. None of the curves gave any indication that a frequency 3 was present, but they all showed frequency 5 quite pronounced; and considering the inaccuracy of the curves analysed, the curves obtained in each case were fairly good sine curves. He now tried for E_{11} by dividing each half of the curve into 33 equal parts, giving him 6 points on the curve. All the three curves showed frequency 11 very good. He had no time to try for any of the others. The results he obtained were in arbitrary units :—

Curve XVII.	Curve XX.	Curve XXI.
$f(\mathrm{E})_{\max} = 38{\cdot}7$	$f(\mathrm{E})_{\max} = 42{\cdot}0$	$f(\mathrm{E})_{\max} = 34$
E_5 ,, $= 2{\cdot}7$	E_5 ,, $= 1{\cdot}2$	E_5 ,, $= 1{\cdot}4$
E_{11} ,, $= 0{\cdot}9$	E_{11} ,, $= 1{\cdot}8$	E_{21} ,, $= 4{\cdot}2$

He thought Mr. Field was quite correct in his main conclusions about the 11th and 13th, but he did not think he was correct in ignoring the

Professor Magnus Maclean.

other harmonics. Indeed, in Curve XVII., the fourth harmonic is more important than the 10th, though the reverse is the case in Curve XXI.

In subtracting the harmonics so found from the original curve, it is quite obvious that there are more harmonics in each of them than the fourth and tenth. He believed from the appearance of them that there are more harmonics than the fourth, tenth, and twelfth, but he had had no time to work further at the curves.

Professor A. Jamieson.

Professor ANDREW JAMIESON said that any one who had carefully studied such books as "The Alternate Current Transformer in Theory and Practice," by Prof. Fleming, and the second or latest enlarged edition of "Alternate Current Working," by Prof. A. Hay, the mathematical parts of Mr. Field's paper were simple, clear, and explicit. Since he was dealing with actual concrete examples, the meaning of several of the formulæ were applied in a more telling manner, than will be found in most treatises upon alternate-current testing and working. Mr. Field had explained by blackboard sketches, in a clearer and more detailed manner than that stated in the proof copy of his paper, the principle, construction, and action of Duddell's oscillograph. He had also dwelt upon its capabilities and shortcomings, and pointed out how he overcame some of its defects. He might explain why he did not photograph the various waves of E.M.F. and current straight from the beam of light *as reflected directly* by the mirror which is fixed to the two phosphor-bronze strips (upon, say, a moving cinematograph film) instead of using the reflections from a second mirror, vibrated synchronously with the first one, but at right angles to its axis? Was there no possibility of an error arising from the use of this special motor and two such mirrors?

Passing over the points touched upon by the previous speakers, and referring at once to the condenser effect produced by electro-static capacity of the underground main high-tension cables, between the power-house and the sub-stations, they found the well-known formula (7) so familiar to submarine cable electricians, viz.:—Current, $C = 2\,\pi\,n\,K\,V$. Then came equation (8), when a current was passed through a coil having a coefficient of self-induction L, where current $C = \frac{V}{2\,\pi\,n\,L}$. And, when these were equated under the conditions stated, we got $(2\,\pi\,n)^2 = \frac{1}{L\,K}$.

Now, as to a mere matter of history, he had had the pleasure of conducting a series of experiments, not only with Thomson and Jenkin's curb-sender, but also with Count Sicardi's curb-signalling key, leaks, and other methods. The object of these experiments was to find out if such devices minimised the retarding effects of electro-static capacity, and thereby increased the speeds of signalling through the long submarine cables of the Eastern Telegraph Co. There, of course, the capacity effects were very much more pronounced than in the case of the short main cables experimented upon by Mr. Field, but the frequencies and the voltages were very much less. However, the increased speeds so obtained by sending a reverse current after each signalling current,

Professor A. Jamieson.

although apparent, did not justify the permanent introduction of any of these methods, since Muirhead's duplex system and Ben. Smith's manual translation, which came to the front about the same time—viz., 1876 to 1878—showed better commercial results.* Then came Prof. S. P. Thompson's proposal to introduce into the cable circuit, at stated intervals, a certain anti-capacity effect by means of self-induction coils. His idea consisted of arranging and fixing these coils to the cable conductor, so that their self-induction should exactly or partially cancel the electro-static capacity effects of the cable. But this bold proposal did not meet with the approbation of practical cable engineers and electricians, owing to the mechanical difficulties of lowering such water-tight coils to the bottom of the ocean whilst paying-out the cable, and of maintaining them in good electrical condition. He thought, however, that this plan could be successfully applied to long subterranean telegraph, telephone, alternate-current lighting, or power transmission cables. Mr. Field had shown how capacity and self-induction might be so joined and adjusted, that the opposition to the current was merely like that of a true ohmic resistance. But, then, his subterranean cables were easily got at; and if ever the "resonance effect" should prove troublesome, or from prior investigation of the conditions should appear to be in any way dangerous, the land electrician could easily make suitable provision against the same.

It was a pity that Mr. Field was leaving Glasgow, because if he had continued his experiments with the oscillograph and tried it directly at the central station, the Section would in all probability have either had a fresh paper or an appendix to his present long and weighty one, stating whether or not the capacity of even two- or three-mile lengths of the Glasgow tramway mains, between the central power-house and any of the sub-stations, did appreciably tone down the wave forms, as illustrated in the diagrams placed before us. He (Professor Jamieson) thought the author had said, that he had not come across a case wherein the resonance effect had proved dangerous to such cables. He was under the impression that the first subterranean cables put down at Londonderry, had been punctured or their insulation resistance seriously diminished by some such action. With such a splendid field for research, he hoped that the Glasgow Tramways'

* [I think that electricians who have opportunities of experimenting upon long submarine cables or artificial lines should carefully study Mr. Field's paper, as well as the experiments by F. Dolezatek and A. Ebelinz on the "Pupin System" of long-distance telephony (see *Electrician*, April and March, 1903). They should then try and devise the simplest and best combination of oscillograph and cinematograph for delineating the curves of charging and discharging or of signalling and of receiving currents, under a great variety of conditions. They could vary the internal resistance and E.M.F. of their sending batteries, the resistance and sensitiveness of their receiving instruments, the capacities of their sending and receiving condensers, the periods of curbing currents, the effects of introducing "Pupin Coils," etc. By trying and systematically comparing the photographic curves derived from these various changes upon cables of different lengths with different ratios of capacity and resistance per naut, they would have a much more searching and surer means of arriving at correct views upon the possibilities of increasing speeds of signalling, than by any of the older methods hitherto adopted.—A. JAMIESON.]

Professor A. Jamieson. oscillograph would not be allowed to rest in its instrument case, but that it might be still further skilfully applied to investigations such as had now been suggested. It could not be placed in better hands than one or other or both of the previous speakers, who would undoubtedly start fair and square at once at the very fountain-head, where only the full pressures of 6,500 volts were to be found! They must not, however, forget to *earth* the centre or neutral point of the armature; for it would be very sad to have to mourn their "loss."

At page 681, Mr. Field says, "We are now getting into the range of the wireless telegraphist." But, surely, one of the principal objects of the tramway or lighting electrical engineer is to keep as far as possible away from such a range of voltage and frequency, when dealing with dielectrics that would be sure to suffer from these effects. One of the chief difficulties which Mr. Marconi had to surmount, was to ascertain how best to arrange and proportion the values of his induction coils and condensers, that for a given primary power he might obtain the most effective electrical "splashes" across his "spark-gap." Both Marconi and his colleagues had made many calculations and experiments, and he understood that he required at Poldhu Station a steam engine of not less than 150 B.H.P. to generate his sending currents. This was, however, a mere nothing to the more powerful Pinkston engines; but happily their currents and circuits were not similarly directed and arranged, or we should have wireless waves sent right round the earth!

Mr. Hird. Mr. W. B. HIRD said: The practical uses to which the oscillograph might be put have been strikingly brought out in this paper, and in this connection there was one point specially noticeable. Mr. Field mentioned that he was unable to obtain good curves when the conditions of the circuit were such as to produce resonance and give great amplitude of the harmonics he was observing, because the oscillograph motor under these conditions fell out of step. Some years ago he had worked with a very rough oscillograph; the curves were obtained by passing the currents to be observed through long wires stretched in a magnetic field, and carrying mirrors, the beam of light from which was thrown, not as in the present instrument on a vibrating, but on a rotating, mirror. The curve was thus drawn out in a long trace, and by working in a dark room a photograph could easily and simply be obtained on a sensitive plate or strip of bromide paper. As many of the phenomena which it would be most interesting to observe were obtained under conditions which were likely to throw the oscillograph motor out of step, it would appear that some such method of doing away with the synchronous motor would have some advantages. Whilst quite agreeing with Mr. Field that a 12th or any even harmonic is inadmissible in curves obtained from the generators he described, because it would make the positive and negative halves of the curves dissimilar, he saw no reason why such a machine should not produce current curves in which the right and left halves of each half-period were unsymmetrical, and he therefore did not see that the fact that an even harmonic would produce such want of symmetry could be quoted as an additional reason for the absence of such harmonics.

Mr. Field, after giving his very ingenious explanation of how the 11th and 13th harmonics in each of the three phases combine to give 12 ripples in the D.C. curve, said that no other pair would combine in the same way; it seemed, however, that the 5th and 7th harmonics, if present in each of the three phases, would combine to form 6 ripples, and the 17th and 19th to form 18 ripples, in exactly the same way, and using the same reasoning as that by which it is shown that the 11th and 13th combine to give 12 ripples. It would be extremely interesting to examine the D.C. curves, and to attempt to increase the amplitude of these harmonics, say, by resonance, so as to detect either 6 or 18 ripples in the curve; and if such were discovered, this would be a striking confirmation of Mr. Field's theory of the genesis of these ripples. Mr. Hird.

Mr. S. Blackley said: After such a lengthy paper, it was very difficult to add anything further to try to satiate the desire for information on this interesting subject, as Mr. Field has suggested that he should do. Resonance was a most fascinating property of the electric circuit, and the importance of its effects on alternating-current systems was frequently under-estimated, if at all considered. It was usually stated that, in practice, the danger accruing from resonance was a myth, or that, no bad effects having resulted so far, the system under consideration was immune from danger of this kind. When they considered that the insulation of our electrical plant and cables must be deteriorating to a certain extent as time goes on, and remembered that in a high-tension system, consisting, say, of transformers, induction motors, and perhaps fifty or sixty miles of good capacity-giving cable, the resonating combinations which might occur are numerous, they should keep in mind the possibility of trouble from resonance effects. He should recommend any one who was inclined to be sceptical on this question to endeavour to obtain a glimpse of the effects (as shown by an oscillograph) which a resonating harmonic of even a moderate frequency had on the E.M.F. wave of an alternator on no load, or to watch the arc formed on opening a high-tension air-break switch in the circuit in which resonance existed. On switching on a few high-tension feeders he had seen the 13th harmonic in Curve XX. resonate to such an extent that all semblance to the original wave form had disappeared, and slightly undulated sinusoidal wave of great amplitude and of a periodicity of 325 cycles per second had taken its place. The question naturally occurred—What would happen if they had a small polyphase synchronous motor running light on this circuit when these cables were switched on? Would the motor, with its field not too strongly excited, prefer to stand still or to speed up to synchronism at the higher frequency? In either case, if they had no previous knowledge of what was going on in the circuit, he expected that the result would be attributed to the speed variation of the engine. Previous to Mr. Field's experiments he had frequently noticed, but could not account for, the sparking which was exhibited all over the high-tension feeder circuit-breakers in the sub-stations as the main engine was starting up in the morning or slowing down at night. This sparking seemed to be statical in nature, and occurred between the woodwork and iron fittings of the Mr. Blackley.

Mr. Blackley.

circuit-breakers. On investigation it was found that the phenomenon always appeared and disappeared at a certain voltage, lower than the normal, as indicated by the high-tension voltmeter in the sub-station, the needle of the instrument remaining stationary for a few seconds while the sparking lasted.* Immediately after the sparking had ceased the voltage began to rise gradually, and nothing further was noticed. They then examined the E.M.F. wave by means of the oscillograph as the voltage fell at night, and found that sparking commenced when the main engine reached a speed such that the frequency corresponding was of a value suitable to produce resonance of one of the harmonics in the wave. The wave form was very similar to that shown in Curve XV. From a consideration of the formula for resonance, viz., $1 = 4 \pi^2 n^2$ K L, the above result would be expected. Since adopting Mr. Field's suggestion as to starting up or shutting down on the high-tension side the sparking had disappeared, except at the normal voltage of 6,500, and only then when a certain length of cable was in circuit. On page 667 Mr. Field referred to the method of arriving at the capacity of the cables by measuring the charging current flowing into them. Perhaps it would be wise to explain that they only expected to arrive at an approximate value of the capacity by the method indicated. The inconsistency in the results was largely due to the fact that the E.M.F. wave of the alternator was not sufficiently near the sinusoid in form to admit of the use of the formula $C = 2 \pi n$ V $K/10^6$. The results served, however, to show how utterly unreliable this method of determination of capacity was even for approximations. It was well-known that the capacity current would be a minimum when the alternator used gave a pure sine wave. In a later test, which he had not had an opportunity to confirm, he measured the current flowing into the cables when the capacity was such as to give the conditions indicated by Curve XX. and again under conditions of more pronounced resonance than in Curve XV. Strangely enough, the results were only consistent if, in the former case, they calculated the capacity using 25 as the value of the frequency, while in the latter the frequency is taken as 13 by 25. The capacity values determined only vary by 3 per cent., the higher value going with the higher frequency.

Dr. J. B. Henderson.

Dr. J. B. HENDERSON said that Mr. Field assumed that the ripples on the alternator E.M.F. wave consisted of sine curves superposed on the fundamental. This might not represent the facts in every case, but it was an assumption as justifiable as that the E.M.F. curves of our old alternators were sine curves, and it might lead to some important general conclusions. Working on this assumption, he had calculated the harmonics, up to the 29th, which were present in the ripples shown in Figs. 7 and 8. Mr. Field had already calculated some of those present in Fig. 7, but it was Fig. 8 which represented the E.M.F. curve of each phase winding of the alternator. The ripples, however, which Mr. Field traced by means of the oscillograph were the ripples on the line E.M.F. curve, and as the alternator windings were connected in star,

* The voltmeter used was of a type which would not read correctly at all frequencies.

Dr. J. B. Henderson.

they were the ripples which resulted from combining two of the curves, like Fig. 8, at 60° phase difference. If we represented the amplitudes of the ripples in Fig. 8 by 1, 2, 2, 2, 2, 1, the amplitudes of the ripples in the resultant wave were 1, 3, 4, 4, 3, 1. It was interesting to notice that all harmonics which were multiples of 3 disappeared by a combination in star and were magnified by a combination in mesh, so that they would cause currents to circulate in the delta. The accompanying table gave the values of the harmonics up to the 29th in the three cases which he had mentioned. It would be noted from the last column that on the line wires the harmonics 11 and 13 were more than thirty times as important as any of the others, except, of course, the first, which synchronised with the fundamental, and was therefore of no account in our comparison. Professor Maclean was, he understood, analysing some of the actual oscillograms taken by Mr. Field. If his analysis did not agree with the last column it simply proved that the sine curve assumption was wrong for this particular alternator. In analysing these ripples he presumed that Professor Maclean had, first of all, corrected the curves for the errors of the oscillograph which Mr. Field mentioned in the paper, as the inequality in the horizontal scale of the oscillogram would introduce much more serious errors in the analysis for the higher harmonics than for the lower.

When we considered the combination of three similar line E.M.F.'s in mesh connection as in the rotary converter armature, the harmonics also combined at phase differences which depended on the particular harmonic considered. The phase difference in the n^{th} harmonic was $n \times 120°$. We found then that the harmonics 1, 7, 13, 19, 25, etc., combined at + 120° phase, while the harmonics 5, 11, 17, 23, etc., combined at — 120° phase. If therefore the fundamentals gave a rotating field in one direction, the harmonics 7, 13, 19, 25, etc., would give rotating fields in the same direction, and the fields due to the harmonics 5, 11, 17, 23 would rotate in the opposite direction. The speed of field rotation was, of course, proportional to the frequency. By reasoning similar to that used by Mr. Field for the 11th and 13th harmonics applied to the rotary converter, we saw that there would be ripples on the direct-current E.M.F. of the rotary having 6, 12, 18, 24, etc., waves per period of the alternating current. Since these were all even harmonics, the direct-current curve should always be a smooth curve, no matter how angular the E.M.F. curve on the alternating side might be with its odd harmonics. The D.C. Curves III., X., and XI. were a strong confirmation of the much greater intensity of the 11th and 13th harmonics than of any of the other harmonics in the A.C. E.M.F., and these curves therefore tended to confirm the figures given in column 14 of the above table. He had to thank Mr. Field for giving him the opportunity of discussing this excellent paper, in which he felt a great interest, as he had conversed with him from time to time about the work, and had been privileged to watch the actual changes taking place in the E.M.F. waves as the cable system was altered.

RELATIVE INTENSITIES OF HARMONICS IN E.M.F. CURVES OF ALTERNATORS WHICH HAVE 2 SLOTS PER POLE PER PHASE.

Harmonic Frequency when Fundamental Frequency is 1.	E.M.F. as represented in Fig. 7. Semi-amplitude of Ripples = b.	E.M.F. as represented in Fig. 8. Probable E.M.F. wave of each phase winding. Semi-amplitudes of Ripples = $b, 2b, 2b, 2b, 2b, b$.	E.M.F. on Cables, due to combination of two phase E.M.F.'s in star connection. Semi-amplitudes of Ripples = $b, 3b, 4b, 4b, 3b, b$.
1	$\frac{4b}{\pi} \times (1 - \frac{1}{26} + \frac{1}{22} = 1{\cdot}0069)$	$\frac{8b}{\pi} \times (\text{Sin}^2 75 \times 1{\cdot}0069 = 0{\cdot}939)$	$\frac{16b}{\pi} \times (\text{Sin}^2 75 \times \frac{\sqrt{3}}{2} \times 1{\cdot}007 = 0{\cdot}814)$
3	$\frac{1}{3} - \frac{1}{30} + \frac{1}{18} = 0{\cdot}3556$	$\text{Sin}^2 45 \times 0{\cdot}3556 = 0{\cdot}1778$	$0{\cdot}0$
5	$\frac{1}{5} - \frac{1}{34} + \frac{1}{14} = 0{\cdot}2420$	$\text{Sin}^2 15 \times 0{\cdot}2420 = 0{\cdot}0162$	$- \text{Sin}^2 15 \times \frac{\sqrt{3}}{2} \times 0{\cdot}242 = -0{\cdot}0140$
7	$\frac{1}{7} - \frac{1}{38} + \frac{1}{10} = 0{\cdot}2166$	$\text{Sin}^2 15 \times 0{\cdot}2166 = 0{\cdot}0145$	$- \text{Sin}^2 15 \times \frac{\sqrt{3}}{2} \times 0{\cdot}217 = -0{\cdot}0125$
9	$\frac{1}{9} - \frac{1}{42} + \frac{1}{6} = 0{\cdot}2540$	$\text{Sin}^2 45 \times 0{\cdot}2540 = 0{\cdot}1270$	
11	$\frac{1}{11} - \frac{1}{46} + \frac{1}{2} = 0{\cdot}5692$	$\text{Sin}^2 75 \times 0{\cdot}5692 = 0{\cdot}5308$	$+ \text{Sin}^2 75 \times \frac{\sqrt{3}}{2} \times 0{\cdot}569 = 0{\cdot}4596$
13	$\frac{1}{13} - \frac{1}{50} - \frac{1}{2} = -0{\cdot}4431$	$\text{Sin}^2 75 \times -0{\cdot}4431 = -0{\cdot}4133$	$- \text{Sin}^2 75 \times \frac{\sqrt{3}}{2} \times 0{\cdot}443 = -0{\cdot}3580$
15	$\frac{1}{15} - \frac{1}{54} - \frac{1}{6} = -0{\cdot}1186$	$\text{Sin}^2 45 \times -0{\cdot}1186 = -0{\cdot}0593$	
17	$\frac{1}{17} - \frac{1}{58} - \frac{1}{10} = -0{\cdot}0584$	$\text{Sin}^2 15 \times -0{\cdot}0584 = -0{\cdot}0039$	$+ \text{Sin}^2 15 \times \frac{\sqrt{3}}{2} \times 0{\cdot}058 = 0{\cdot}0034$
19	$\frac{1}{19} - \frac{1}{62} - \frac{1}{14} = -0{\cdot}0349$	$\text{Sin}^2 15 \times -0{\cdot}0349 = -0{\cdot}0023$	$+ \text{Sin}^2 15 \times \frac{\sqrt{3}}{2} \times 0{\cdot}035 = 0{\cdot}0020$
21	$\frac{1}{21} - \frac{1}{66} - \frac{1}{18} = -0{\cdot}0231$	$\text{Sin}^2 45 \times -0{\cdot}0331 = -0{\cdot}0115$	
23	$\frac{1}{23} - \frac{1}{70} - \frac{1}{22} = -0{\cdot}0162$	$\text{Sin}^2 75 \times -0{\cdot}0162 = -0{\cdot}0151$	$- \text{Sin}^2 75 \times \frac{\sqrt{3}}{2} \times 0{\cdot}016 = -0{\cdot}0130$
25	$\frac{1}{25} - \frac{1}{74} - \frac{1}{26} = -0{\cdot}0120$	$\text{Sin}^2 75 \times -0{\cdot}0120 = -0{\cdot}0111$	$+ \text{Sin}^2 75 \times \frac{\sqrt{3}}{2} \times 0{\cdot}012 = -0{\cdot}0097$
27	$\frac{1}{27} - \frac{1}{78} - \frac{1}{30} = -0{\cdot}0091$	$\text{Sin}^2 45 \times -0{\cdot}0091 = -0{\cdot}0046$	
29	$\frac{1}{29} - \frac{1}{82} - \frac{1}{34} = -0{\cdot}0071$	$\text{Sin}^2 15 \times -0{\cdot}0071 = -0{\cdot}0047$	$\text{Sin}^2 15 \times \frac{\sqrt{3}}{2} \times 0{\cdot}007 = 0{\cdot}0004$

Prof. Gray.

Professor A. GRAY said that he had read Mr. Field's paper with much interest, and regarded it as an example of the benefit to be derived from a free use of Mr. Duddell's beautiful instrument. When once the curves had been thus drawn, the well-known methods of harmonic analysis could be at once applied to separate out the harmonics which existed in the wave forms, and thus to exhibit the fundamental components of the action of the machines. This was a further step of some importance, and perhaps some of the mechanical analysers which had been devised for periodic curves might be made use of in this connection. It was only by such registration of the behaviour of machines and subsequent analysis that we could obtain light upon the various matters which were still obscure in the action of generators of different kinds. He had felt specially interested in the discussion on resonance, and in that part of the paper dealing with the alternating charge and discharge of cables. The curves, though small in scale and therefore difficult to examine closely, were almost surprisingly identical with the curves that one could draw for the oscillatory subsidence of the charge of a condenser from the theoretical equation, obtained by supposing the plates connected by a coil of definite unvarying self-inductance. The crests of the successive ripples lay on the exponential curve (*e.g.*, Figs. 24, 26, etc., if it was that these had been drawn for actual cases by discharge through the inductive coils of a machine) which one would have expected in such a case. Now, the self-inductance of the circuit could not be constant in this case, but must be some function of the current, and therefore of the time; and the exact solution of the differential equation could not be given unless this function was known, and almost certainly only by approximation even then. He would like to see a large scale of curves for this case. In the meantime, it was interesting to have the results given in the paper. The fact that the potential on a cable at charge or at discharge might be very much greater than the working potential was, of course, a result that might have been anticipated without experiment, but Mr. Field's exhibition of it in this way must be of great value to practical men in calling attention to the matter, and in causing those in charge of plant of this description to realise the danger that probably had not occurred to anybody.

There were a good many corrections required in the proof, which would no doubt be made by the author, and he did not desire to make these in any way a matter of criticism. But some of the more mathematical slips should be carefully scrutinised. There were some points in connection with the curves which he had not yet had time to consider, which he should like to go into at some future time—for example, as to curves XXXVI., which were very interesting.[1]

The only other remark he would make at present was as to the definition of self-inductance. There were two definitions current; one was the equation

$$E = R\,C + L\,\frac{d\,C}{d\,t}, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

in which it denoted the coefficient of the time rate of variation of the current $d\,C/d\,t$ in the expression for the electromotive force in the

Prof. Gray. circuit. In a circuit containing iron, of course, L was not a constant, but was the rate of variation $d\,N/d\,C$ of the total number N of lines of force through the circuit with variation of the current C. This definition had, no doubt, its advantages for dynamo work, otherwise practical men would not employ it, and he was not to be taken as objecting to it. But there was the other sense in which the term self-inductance had been employed by most of the pioneers in electro-magnetic theory; the defining equation was here

$$N = L\,C \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

where N had the same meaning as before, L was not here a constant either, and its relation to the L of the former equation was easily exhibited. We had clearly from the equation just written

$$\frac{d\,N}{d\,t} = l\,\epsilon\,\frac{d\,N}{d\,C}\,\frac{d\,C}{d\,t}$$

$$= \left(L + C\,\frac{d\,L}{d\,C}\right)\frac{d\,C}{d\,t}$$

by (2), so that if we denoted the L defined by equation (1), that is $d\,N/d\,C$ by L′, and use L for the quantity defined by equation (2), we had—

$$L' = L + C\,\frac{d\,L}{d\,C}.$$

The difference was that L′ united in one symbol the two parts of the coefficient of $d\,C/d\,t$ in the equation of electromotive force (1); and the two values coincided in the case of constant self-inductance. As he had indicated, there was this double use of the term self-inductance, which was, he thought, a pity. One definition was as directly applicable to alternating circuits as the other; the important thing to remember in either case was that when there was iron present the self-inductance was variable. The matter was entirely one of definition, and in that the convenience of all concerned should, of course, be consulted.

Perhaps it was unnecessary, but there was no warning given, so far as he could see, that the whole mathematical disquisition commencing on page 677 to near the end proceeded on the assumption that L was constant, which, of course, it was far from being in the circuits of the machines usually employed in the work referred to.

The paper represented a vast amount of good work, though in its present uncorrected form its complete perusal was a matter of considerable difficulty. He hoped that it would be printed, so that its results might be fully understood and appreciated.

The Three Hundred and Ninetieth Ordinary General Meeting of the Institution was held at the Institution of Civil Engineers, Great George Street, Westminster, on Thursday evening, March 12th, 1903—Mr. JAMES SWINBURNE, President, in the chair.

The minutes of the Ordinary General Meeting of February 26th, 1903, were, by permission of the Meeting, taken as read and signed by the President.

The names of new candidates for election into the Institution were also taken as read, and it was ordered that their names should be suspended in the Library.

The following list of transfers was published as having been approved by the Council :—

From the class of Associate Members to that of Members—

Ralph Henry Covernton.

From the class of Associates to that of Associate Members—

Alfred S. L. Barnes	Andrew Stewart.
George Richard Drummond.	E. Taylor.
Richard Christopher Simpson.	H. Osborn Wraith.

Warwick Makinson.

From the class of Students to that of Associates—

Harold Thomas Brown.	Frederick Edward Kennard.

Cuthbert John Greene.

Messrs. Quin and Speight were appointed scrutineers of the ballot for the election of new members.

Donations to the *Library* were announced as having been received since the last meeting from the Italian Ambassador ; to the *Building Fund* from Messrs. R. C. Barker, J. R. Bedford, W. J. Bishop, R. H. Burnham, A. D. Constable, R. A. Dawbarn, F. W. E. Edgcumbe, W. Fennell, A. G. Hansard, E. R. Harvey, C. E. Hodgkin, G. F. R. Jacomb-Hood, Lord Kelvin, H. Kilgour, H. Lea, A. E. Levins, F. H. Nicholson, M. Robinson, H. Seward, F. W. Topping, C. E. Wigg, and A. P. Whitehead ; and to the *Benevolent Fund* from Messrs. W. J. Bishop, R. V. Boyle, M. S. Chambers, K. W. E. Edgcumbe, J. W. Fletcher, Prof. R. T. Glazebrook, E. P. Harvey, A. E. Levin, M. Robinson, A. P. Trotter, H. J. Wagg, and R. W. Weekes, to whom the thanks of the meeting were duly accorded.

The PRESIDENT: It will be within the knowledge of many of the members that the Council has been engaged for some time past in the preparation of Wiring Rules. A committee has sat and worked very hard in connection with the subject, and we have now drafted a set of Wiring Rules, which have been passed by the Council, having first been dealt with word by word by a very large and representative Committee. The Wiring Rules have been submitted to the Incorporated Municipal Electrical Association, which, after making some slight alterations and improvements, has adopted them. That body had a representative on the Committee. Several of the largest Fire Insurance Companies have also adopted the Rules. The Wiring Rules at present issued by different bodies are not only divergent, but in some cases incompatible with the new set of Rules as drawn up by this Institution. We hope that our Rules will gradually supersede others, and introduce uniformity in standardisation. It is proposed to send them to supply engineers, consulting engineers and the Power Companies and contractors, and it is hoped that members will use every possible effort to get the Rules adopted, and will use them themselves whenever they possibly can, and so gradually get them introduced universally. A Standing Committee has been appointed, so that if any alterations arise from time to time they can be dealt with as they arise. It will not be necessary to wait until there is any very large improvement needed. Any small alterations can be made practically at once if it is found necessary.

There is another matter which has been before the Council for some time to which I desire to draw attention, namely, that a Telegraph Conference is to be held in England in May or June of this year. Most of us in our days come to listen to papers in this Institution which are not Telegraph papers, but we must remember that Telegraphy was the original work of this Institution. We were originally a telegraph society, and although we do not now get so many papers and novelties on the subject of telegraph work, telegraphy is by no means correspondingly unimportant. In fact, it is the other way about; telegraphy has got to such a high pitch of perfection that there is very little to bring forward before the Society. Telegraphy is of enormous importance to this Institution. I may remind you that this Congress is an International affair, and will be a very large and important gathering; the Council therefore feels that we ought to do everything we can to entertain the Congress, and to take our proper part in the proceedings. But a difficulty at once occurs, because it will be held at the end of one session and the beginning of the next. The Council feels, and has felt all along, that the right thing to do is to have one President to take charge of the Institution over that time, and to have a President selected for that purpose. There is one man in particular who is exactly the right man to be President under those circumstances, and I have little doubt the Council will select him. In order that the Council may have the opportunity of selecting a President, and of his being elected so as to preside during the Congress, and to give him ample time to make the needful preparations, I propose to send in my own resignation between this and the

next meeting. Then, by the Regulations, the Council will be able to nominate their own new President, who will take charge on that election until the General Meeting. After the General Meeting, of course, the President has to be nominated and elected in the usual way by the Institution; but when you know whom the Council proposes as President I know you will be unanimous in electing him for the following year also.

I will now call on Mr. Fawssett to read the paper which he has written together with Mr. Constable. It is most unfortunate that Mr. Constable is very seriously ill. He was not able to be here on the last occasion, and he is not able to be here to-night, but we hope very much he will be able to be present at the next meeting, and give him our best sympathies.

DISTRIBUTION LOSSES IN ELECTRIC SUPPLY SYSTEMS.

By A. D. CONSTABLE, Associate-Member, and
E. FAWSSETT, Associate.

"*Dare quam accipere.*" This is a motto not universally followed by electrical engineers in the course of their business, yet in the case of a particular supply-station of quite moderate capacity, over 800 tons of coal are annually given gratis to warm up the town, and the authorities, besides not receiving one penny towards the cost of it, do not even receive the thanks of the residents for the grateful warmth provided.

Few central station engineers expect to get paid for more than 75 per cent. of the energy they generate. Of the remaining 25 per cent. about four-fifths is absolutely wasted; and worse than that, it increases the waste which would otherwise take place. The other fifth is used in the station itself for lighting and other purposes, and cannot be said to be actually wasted, although it is unproductive as regards revenue.

It is worth while considering how this wasted 20 per cent. is made up, and whether it is possible to reduce it in any way, since it costs as much to generate each unit wasted as each unit sold.

The figures given in this paper refer to the Croydon Electricity Works.

The total losses incurred between the generator terminals and the consumers' terminals, leaving out of consideration the units used in the station for field excitation, lighting and driving auxiliaries, may be subdivided under the following five headings:—

(1) Losses in Switchboards and Connections.
(2) Losses in High Pressure Feeders.
(3) Losses in Transformers.
(4) Losses in Low Pressure Cables.
(5) Losses in Meters.

These are discussed under the various headings, Nos. 2 and 4 being taken together.

Switchboard Losses.

Notwithstanding the fact that we are not dealing with a material substance like gas, which has to be conveyed through pipes with innumerable possibilities of leakage, there is an actual loss in transmitting electrical energy to the consumers of over 20 per cent. of the total energy sent out of the station.

The actual loss by leakage is extremely small; by far the larger part is, of course, due to our having no perfect conductors at our disposal, and this loss due to conductor resistance is infinitely more important than the corresponding loss of pressure due to pipe friction.

TABLE No. I.

Losses Up To and Including Main Switchboard.

	System of Supply.	Maximum Output.	Approximate Mean Loss in per cent. of Annual Output.
1	2,000 volts alt. cur. one pole earthed.	1,250 K.W.	0·43
2	500 volts direct cur. Tramways (A)	500 K.W.	0·42
3	500 volts direct cur. Tramways (B)	400 K.W.	0·30

Average loss in Substation Switchgear (System 1) and connections: 0·10 per cent. of output.

It becomes appreciable even at the feeder terminals on the main switchboard. Table I. gives these initial losses in the case of three different sets of plant. The values were obtained by measurement, and may be taken as a very fair average of the usual existing conditions. Careful arrangement of the relative positions of the switchboard and generators and simple design of the switchboard will, to some extent, eliminate these losses.

The minimum number of instruments should be installed, and these should be connected with as few joints as possible; ammeters should preferably be of the shunted type. Some switchboard erectors have a natural incapacity for screwing connections up tight, and some instrument makers are afraid of giving their customers too much metal; the authors have come across several cases of joints which have welded themselves together, of bus-bars running at or over 200° F., and even of switch-gear working at a temperature of 150° F. at normal full load.

One square foot of dull copper surface running at 10° F. above the temperature of the air will continuously dissipate the heat produced by

the absorption of about 16 watts, or, if the excess temperature is 50° F. the watts will be about 60.

Main fuses should be avoided where possible, not only because they are objectionable in themselves, but to be of use they must run warm and consequently waste energy.

It may be said that these are refinements beneath the notice of the practical engineer, but in the station under consideration, which is of fairly modern design with an output of only 1,250 k.w. at the maximum, the total loss per annum in the switch-gear and connections alone (including those in the substation) amount to 10,000 units, which, it will be readily granted, shows considerable room for improvement.

In those cases where the generator pressure is raised before transmission, in addition to the switchboard losses there are those in the step-up transformers to be taken into consideration; these are dealt with in the section on transformer losses later on.

Cable Losses.

Of all the losses in the system, the cable losses are the most important and those that can be least easily reduced. The larger part of this paper will, therefore, be devoted to their consideration.

The total losses in the cables may be split up into three components :—

(1) C^2R losses in the dielectric.

(2) C^2R losses in the conductor.

(3) Losses due to what may be called dielectric hysteresis.

The first may be shortly dismissed; it is, as stated above, generally very small, at any rate in the main feeders of a well laid out system.

The total insulation resistance between poles of this system of 2,000-volt feeders, comprising about 25 miles of concentric cable in nine separate feeders (ranging from ·15 □″ to ·025 □″) was 0·10 Ω, including switchboards at both ends. This, at a pressure of 2,000 volts, corresponds to a total leakage current of 0·02 ampere, or a loss of only 40 watts, or 350 units per annum, *i.e.*, 14 units per mile of high-tension cable.

The insulation of the low-tension network is, of course, very much less, and can, with difficulty, be measured; if we include all switchgear, network boxes, and services, it may be about 1,000 ω for 50 miles of cable, and at 200 volts the lost watts will be again 40, or 7 units per mile of cable per annum. The 50 miles of low-tension cable roughly correspond to the 25 miles of high-tension cable, so that the total leakage loss is only 700 units per annum.

The above figures give a rough idea of what may be expected in this direction, and it is useless to go into greater detail, owing to the enormous variations of insulation met with in practice. The insulation of a low-tension network may be of the order of ohms without being detected, for a long time. A case in a neighbouring system once came under the authors' notice in which there was a leak sufficient to raise a mass of concrete round a bunch of cables to a red heat before it was noticed; this is, happily, a very exceptional case.

The second cause of loss, viz., that due to C^2R in the cables, is of the greatest importance, and it also lends itself, in the case of feeders at least, to fairly accurate calculation. In the case of the low-tension network, however, the loss can only be approximately ascertained.

Table II. gives the C^2R losses for the whole of the Croydon system of mains. They have been worked out for each quarter of the year, the basis of the calculation being the load curves shown in Diagram No. I. The upper full curve is the load curve for a December week-day. The lower curve is the load for a day in July, and the middle curve is the mean for September and March. The curve for March is rather higher than that for September, owing no doubt to the latter being the holiday season. In working out the losses, these curves have been assumed to be the mean curves for the corresponding quarter, and the current in each separate feeder and distributor has been assumed to follow the same law as the total current.

TABLE No. II.

C^2R Losses in Cables.

Maximum Load Supplied: 1,250 K.W.

Description of Cables.	C^2R Loss in Units per Annum.
2,000 volt Feeders and Sub-feeders. About 25 miles, 0·15 sq. inch section to 0·025 sq. inch	47,200
400 and 200 volt Distributors. About 50 miles, 0·40 sq. inch section to 0·10 sq. inch	66,200
H.T. Arc Cables, 10·6 miles, 0·023 sq. inch Section (series)	11,400
L.T. Arc Cables. About 20 miles, 0·06 sq. inch and 0·025 sq. inch section	25,800
Total	150,600

This is, of course, not strictly accurate, but is near enough for the purpose of this calculation. An exception has been made in the case of the public lighting load, as this, of course, follows a different law. The lower dotted lines in the diagram are the load curves for public lighting, and are calculated from Diagram No. II. as a basis, there being in this case a total of 400 arc-lamps, 180 of which are switched off at about midnight. The greater part of these lamps are fed in parallel at 200 volts alternating, from low-tension mains used for no other purpose.

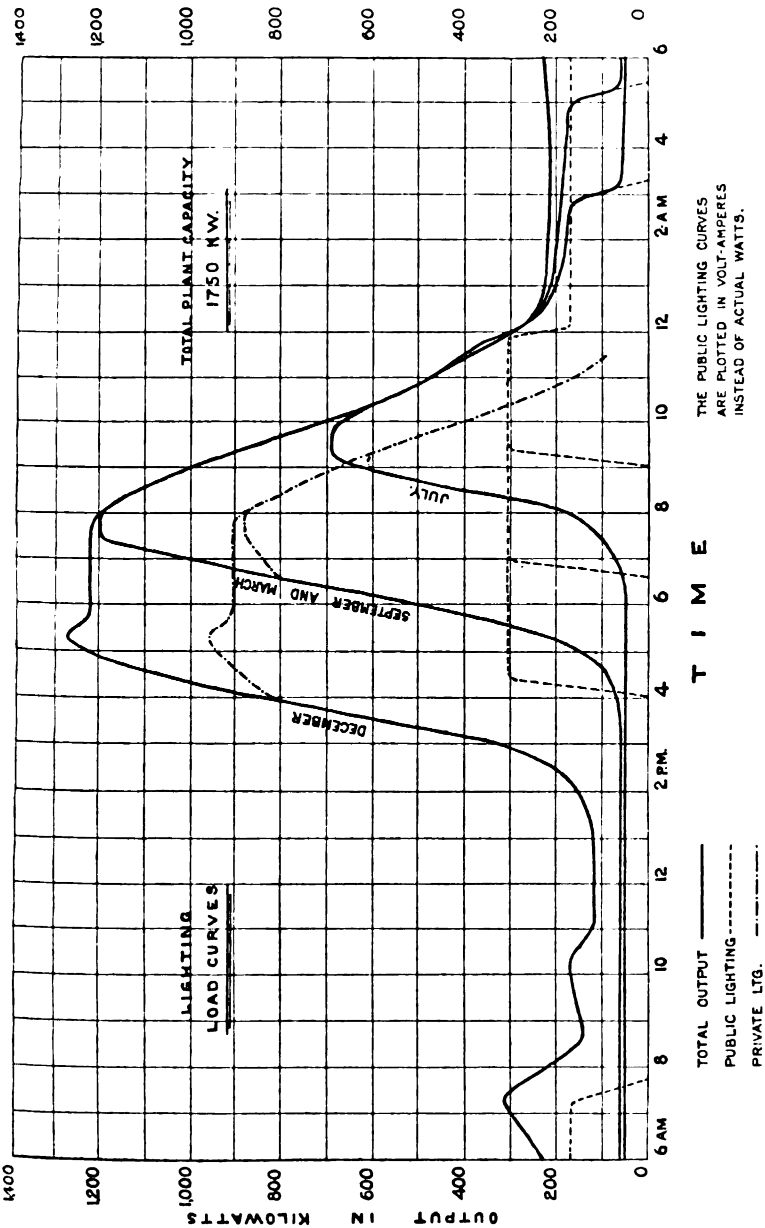

LIGHTING
LOAD CURVES
TOTAL PLANT CAPACITY
1750 K.W.
JULY
SEPTEMBER AND MARCH
DECEMBER
1400
1200
1,000
800
600
400
200
0
OUTPUT IN KILOWATTS
6 AM
8
10
12
2 P.M.
4
6
8
10
12
2 AM
4
6
TIME
TOTAL OUTPUT
PUBLIC LIGHTING
PRIVATE LTG.
THE PUBLIC LIGHTING CURVES
ARE PLOTTED IN VOLT-AMPERES
INSTEAD OF ACTUAL WATTS.

Diagram No. I.

These mains, however, take their supply from the same low-tension bus-bars in the substations as the private supply. There are in addition four high-tension series circuits supplying together 134 lamps.

The upper dotted curves are the private lighting load curves for the respective quarters, and are used to calculate the C^2R losses in the low-tension network, in conjunction with the observed average drop in potential between the substations and consumers' terminals, which latter averages four or five volts.

We now pass on to the third heading—"Losses due to dielectric hysteresis," to use the term for want of a better one. After the very thorough way in which this question was discussed recently before this Institution, perhaps an apology is needed for again bringing up the subject. As the question was not finally settled, it was the intention of the authors to experiment thoroughly on the large system of high-

HOURS OF PUBLIC LIGHTING

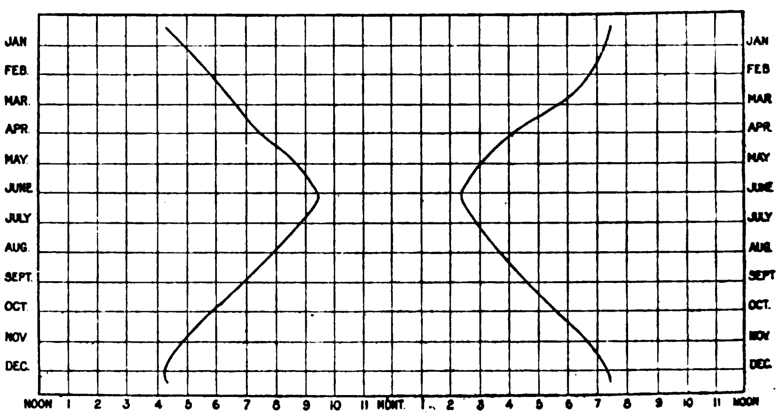


DIAGRAM NO. II.

tension cables at Croydon, and find out once for all what the true losses incurred in actual working were; an additional incentive was the desire to again demonstrate that, contrary to the usual belief, it was possible in certain cases to obtain a power-factor as high as 0·10 in a cable, as was stated to be the case in Mr. Mordey's paper and in Mr. Minshall's contribution to the discussion thereon. The latter is conclusively proved by the figures in Table IV.

The more ambitious scheme was doomed to partial disappointment at any rate; it has been found a task of very great difficulty to obtain these losses with any reasonable accuracy with the instruments available in a fairly well equipped test-room. Numerous experiments have been made, but owing to the interruptions due to the necessary routine of work of a central station in an exceptionally busy year, these results are somewhat meagre and inconclusive. This section of the paper is, therefore, rather of the nature of a series of suggestions, and it is hoped that the discussion will produce further data.

The experiments are here discussed seriatim, as some of the methods adopted and the difficulties experienced, as well as the few results obtained, may be of interest.

The methods available for this investigation are :—

(1) Direct measurement of watts used in the cable by a wattmeter either with or without a choker to improve the power-factor of the circuit.

(2) Calculation of watts from plotted curves of volts and current or from oscillograph records.

(3) Direct measurement of increased power necessary to drive an alternator when a cable is switched on.

(4) Calorimetric method, *i.e.*, measurement of rise of temperature due to lost watts.

(5) Calculation of watts lost from known data and law of current variation determined experimentally.

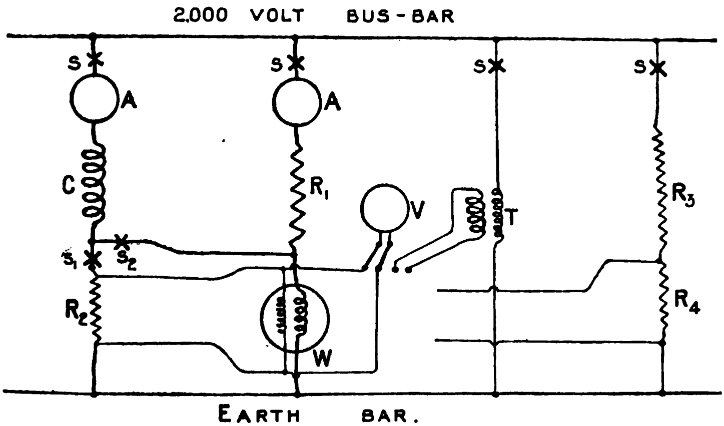


DIAGRAM No. III.

The first three methods have been used in this investigation with the results discussed below. Method (4) is one difficult of application and impossible in the case of cables in the ground, and is in any case open to many sources of error.

Method (5) has not been attempted, as sufficient data as to the law of current variation have not been obtained.

With regard to method (1), the first thing necessary was to discover what reliance could be placed on the readings of the ordinary commercial wattmeters at our disposal, when used on various power-factors.

Three wattmeters were used, viz. (1) a Swinburne with no unnecessary metal parts. This wattmeter had three different sets of current coils to give different sensibilities. (2) and (3) Thomson inclined coil wattmeters of different ranges with frames partly of metal. All three had large non-inductive resistances in series with the pressure coil, and were wound for 250 volts.

TABLE No. III.

Wattmeter Constants.

Date.	Nature of Load.	Power Factor.	Constant.	Scale Rdgs.	Voltage Curve similar to	Remarks.
	SWINBURNE WATTMETER.					
17-7-01	Non-Inductive Lamp Bank	1·00	9·92	15	No. 10 Sheet A.	Original Fine Wire Current Coil. about No. 16 S.W.G.
"	do. ..	1·00	10·05	21		
"	do. ..	1·00	9·83	30		
"	do. ..	1·00	9·90	56		
"	do. ..	1·00	9·88	80		
4-8-01	do. ..	1·00	9·93	14	12, St. B.	
6-8-01	do. ..	1·00	9·96	15	No. 10 Sheet A.	
"	do. ..	1·00	10·01	23		
17-8-01	do. ..	1·00	9·93	39		
6-8-01	Inductive, Current leading ..	0·129	9·03	2·5	No. 10 Sheet A.	
"	do. ..	0·374	9·98	61		
17-8-01	do. ..	0·141	10·20	5		
"	do. ..	0·143	10·17	3		
4-8-01	Do., Cur. lagging ..	0·032	9·74	2	No. 12 Sheet B.	
"	do. ..	0·304	9·38	16		
6-8-01	do. ..	0·034	10·26	2·5	No. 10 Sheet A.	
17-8-01	do. ..	0·035	10·90	2·5		
8-9-01	Do., Cur. leading ..	0·129	1·262	14	No. 10 Sheet A.	Current Coil re-wound with fine wire, about No. 26. S.W.G.
"	do. ..	0·129	1·195	30		
"	do. ..	0·142	1·256	25		
"	do. ..	0·142	1·193	45		
"	Do., Cur. lagging ..	0·034	0·952	25		
"	Do., Cur. leading ..	0·138	1·189	35	12, St. B.	
10-9-01	Non-inductive lamp bank	1·000	1·278	70–90	10, St. A.	Cur. Coil rewound as above, and also new volt coil.
	THOMSON WATTMETER 1 AMP. RANGE.					
4-8-01	Non-Inductive Lamp Bank	1·00	1·027	140	No. 12 Sheet B.	As used in all experiments after 4-8-01.
7-8-01	do. ..	1·00	1·00	60–140		
6-9-01	do. ..	1·00	1·063	140	No. 10 Sheet A.	
"	Induc-Cur. leading..	0·141	1·016	30		
"	do. ..	0·141	1·040	50		
4-8-01	Do., Cur. lagging ..	0·032	1·271	13	No. 12 Sheet B.	
"	do. ..	0·304	1·026	150		
6-9-01	do. ..	0·035	1·015	22	10, St. A.	
	THOMSON WATTMETER, 10 AMP. RANGE.					
6-9-01	Non-inductive Lamp Bank	1·00	9·78	21	No. 10. Sheet A.	Not used owing to variable constant.
"	do. ..	1·00	9·96	37		
"	Inductive, Current leading ..	0·142	6·60	3·5		
"	do. ..	0·143	7·81	6		
17-8-01	Do., Cur. lagging ..	0·035	8·83	3		

The voltage was reduced in the ratio of about 10 : 1 by means of a bank of lamps, the actual ratio being measured for each set of readings; the voltage on the wattmeter was measured on a standard electrostatic instrument, and the full voltage was reduced by a transformer of known ratio and measured on the same voltmeter.

Diagram No. III. shows the connections for calibrating the wattmeters initially; it is almost self-explanatory, and power-factors of about 0·03 and 0·35 with current lagging, 0·14 with current leading, and unity were used in the calibration. The leading current was

obtained by passing a current through the series coil of the wattmeter in phase with the applied volts and connecting the pressure coil to a non-inductive resistance in series with a choker. The wattmeter is shown connected in this way in the diagram.

The power-factor of the ironless choker circuit of course can be calculated with very fair accuracy. The choker, as used throughout, consisted of 112 lbs. of No. 16 copper wire wound on a wooden drum. A thermometer was embedded in the winding and the temperature was taken for each reading.

The resistance, in series with the choker, consisted of lamps. It has been assumed throughout that the lamp banks used were non-inductive, no difference in phase between current and applied volts being observable on the oscillograph used in these experiments.

Table III. gives the constants obtained for the wattmeters under the various conditions.

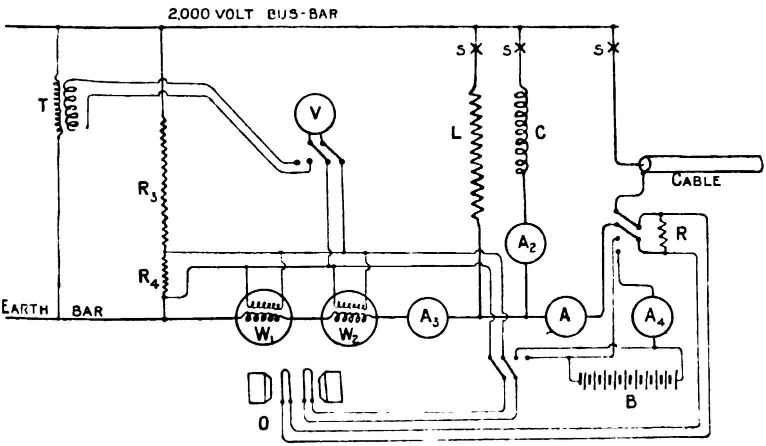


DIAGRAM No. IV.

It will be noticed that the Swinburne Wattmeter and the small range Thomson Wattmeter give fairly consistent results, although there are considerable variations with the different power-factors, chiefly due, in all probability, to the various wave-forms of the applied voltage. There are also variations in the constant obtained under the same conditions at different times, but as the constant used in working out the cable watts was that obtained under the most nearly corresponding conditions, and at the same time in most cases, the errors should not be large. Very low power-factors with leading current were not obtainable for calibration owing to the lack of a larger choker.

In the case of the larger range Thomson instrument the constants vary from 6·6 to nearly 10·0, notwithstanding the maker's statement that the instrument is correct for all power-factors and all wave-forms; this apparently applies between certain limits only. The readings of this instrument were, therefore, rejected. In the later experiments by

a slight modification of the connections it was possible to calibrate the wattmeter in use, on a load with leading current, for every reading, and this was done in each case.

The actual connections used in the cable experiments are shown in Diagram No. IV., two wattmeters being generally used in series as a check.

Readings were taken, both with and without the choker C in parallel with the cable.

L in the diagram is a bank of lamps, used in the earlier experiments in calibrating the wattmeters with PF = 1. The ammeters were all compared with a low-reading Siemens Dynamometer, but the final standard was an Elliott's Voltmeter, used in conjunction with a standard ohm.

The arrangement on the right of the diagram at the bottom is for the purpose of calibrating the oscillograph. A voltage of 130 D.C. could be applied to the oscillograph without altering the connections and the value of the deflection in volts thus obtained.

In the same way a known direct current could be passed through the non-inductive current shunt R, and the value of the oscillograph deflection in amperes ascertained.

The principal results obtained are given in Table IV., and the agreement of the watts absorbed in the cable as measured by the wattmeters and by working out the oscillograph curve, is in some cases good. These curves were worked out by taking the mean value of the instantaneous watts for 22, and in some cases 44, equi-distant points of time in the diagram of one complete period.

In several instances it will be noticed that the R.M.S. value of the voltage obtained from the oscillograph diagrams is higher than that measured on the voltmeter. This is probably due to the fact that the calibration was made with 130 volts instead of 200 volts, and the resistance of the lamps in series with the voltage strip was higher than it was in the actual experiment, thus making the oscillograph appear less sensitive than it really was.

In the case of Experiment No. 15 and onwards this possible error did not occur, as there were no lamps in series with the voltage strip, and the agreement is better, though in this case the voltage as measured is slightly higher than that obtained by working out the curves.

The watts taken by the choker alone have been also worked out from the oscillograph curves (Curves D), and the agreement with the calculated watts is in this case good.

Some experiments had to be made without the oscillograph, owing to its being out of order, so that in these cases the watts are only those obtained on the wattmeter. Some were made without a wattmeter and some without independently calibrating the oscillograph (see last column in Table IV.). In the four cases in which watts have been obtained, both from the oscillograph records and with a wattmeter, the two values are of the same order, but they do not agree as well as could be wished.

This is, no doubt, explained partly by the shape of the waves. In curves of shapes E, F, and G, for example, owing to the almost vertical-

Exp. No.	Date of Experiment.	Cable No.	Description.	Length. Yards.	Section. □″
1	21-7-01	4	Conc. jute insulated, lead-sheathed, armoured, direct in ground	2,100	0·10
2	8-9-01	4			
3	8-9-01	4			
4	14-7-01	7	Conc. V.B. insulated, laid solid in iron trough with iron cover, designed for 5,000 volts, worked at 2,000 volts	7,290	0·10
5	21-7-01	7			
6	4-8-01	7			
7	21-7-01	7			
8	4-8-01	7			
9	4-8-01	9	Conc. jute insulated, V.B. sheathed, laid solid in wood trough with No. 10	2,440	0·15
10	8-9-01	9			
11	8-9-01	9			
12	8-9-01	10	Conc. paper ins. V.B.S., laid solid in iron trough with tile cover, W.P. 5,000 v.	2,400	0·15
13	8-9-01	10			
14	4-8-01	Choking Coil	112 lb. No. 16 S.W.G., copper; wound without iron	—	—
15	-10-02	11	Concent. paper insulation V.B.S., laid solid in iron trough with tile cover, working pressure 5,000 volts	6,340	0·10
16	-10-02	11			
17	-10-02	11			
18	-7-02	11			
19	-7-02	11			
20	-7-02	11			
21	-10-02	12	See Note (i.) at foot	21,660	See Note (i.)
—	—	—	—	—	—

NOTES:—(i.) Cable No. 12 consisted of Cables Nos. 9, 13, 14, 10, 11
type as No. 10.
(ii.) Worked out result of Curves E, F, and G probably ver
(iii.) Thomson wattmeter used in series with Swinburne in
(iv.) No wattmeter used in Experiments 15 to 21. Watts w
(v.) The Swinburne wattmeter with original fine wire coil
Nos. 2, 3, 10, 11, 12, 13.

sided peaks, it is impossible to work out the watts even with approximate accuracy. A horizontal difference of ·01 inch in the relative position of one of the peaks of the curves of current and volts will totally alter the power-factor indicated.

If it had been possible to obtain photographic records some improvement in accuracy would have resulted, but as it is, with curves traced by hand, very little reliance can be placed on the worked out power-factor of the very peaked waves.

On the other hand, simpler wave-forms can be worked out fairly accurately; Curve D for example. Referring again to the table, it will be noticed that very great discrepancies occur between various sets of readings on the same cable and also between the results obtained with the choker in parallel with the cable and without it. The former results should be the more accurate, owing to the higher power-factor.

Such figures are not very conclusive, but they have been obtained with all proper precautions, and it is hoped that some explanations of the discrepancies may be suggested.

Part of the differences may be due to the effect of alteration of wave-form (1) on the actual losses, and (2) on the instrument indications.

It has not been definitely proved whether the power-factor of a cable is altered by alteration of the wave-form of the applied voltage, or not. On the whole, it may be inferred that it is altered to some extent, but not largely. With wave-forms as in curves E, F and G, the power-factor for a long paper-insulated cable comes out at about 0·014 averaging the three, and with curves H, I and J for the same cable and approximately the same voltage it is 0·08. A wattmeter was not used in this case.

This enormous difference cannot be put down wholly to the difference of wave-form, but is most probably due to the inaccuracy in working out the very peaked waves of the first set of curves, and the agreement of the three is probably more coincidence than anything else. The value obtained from the last three curves has been taken as the more probably correct.

With regard to the effect of wave-form on the other instruments used, it is stated by Benischke that there may be a difference of 10 per cent. in the readings of electromagnetic instruments with flat and peaked waves.

In calibrating the various instruments used, differences amounting to about 5 per cent. were found when using different wave-forms, the sub-standard being a Siemens Dynamometer with practically no metal parts in the frame, and this should read sensibly the same for different wave-forms and frequencies. The Thomson Ammeters read higher on the smoother waves. In working out the experiments the calibration with the particular wave-form of the experiment was that used. In Table III., giving the wattmeter constants obtained at different times, the form of wave is noted for each set of readings.

It was found that the voltage across the terminals of the current coil of the Swinburne Wattmeter (using the fine wire coil) varied in the

ratio of about 1 : 3 in the various experiments owing to the difference in the current frequency.

It is difficult to say to what extent a wattmeter may be relied on when the current has about double the frequency of the applied voltage.

In order to overcome the difficulty of very small scale readings on the wattmeters, the current coils were in most cases heavily overrun, a short-circuiting switch being put in except when taking readings.

It is interesting to note that in one experiment, not recorded in the table, the wattmeter gave a higher reading when short-circuited than when the current coil was in circuit, no doubt due to currents induced by the voltage coil, which was in circuit.

In all the recorded experiments the measuring instruments were placed in the earthed outer of the cables, as it was found that the readings were practically identical with those obtained with the instruments on the inner, and the safety of the arrangement was much greater.

It was considered a matter of interest to find out how the wave-forms and values of current and voltage, varied at different points in the length of a cable, if at all. An experiment was, therefore, made as follows:—

Six long cables were joined in series, and readings of current and voltage and tracings of the wave-forms were taken at each end and at the junction of the two middle cables. Four ends being accessible at the power-station, it was not necessary to move the oscillograph at all.

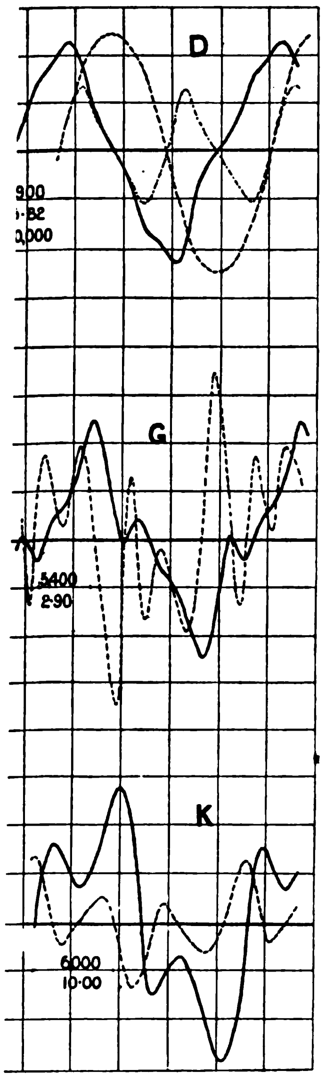
The readings taken at the end at which the voltage was applied are recorded in Experiment No. 12, Table IV., as are also the lengths and sections of the various cables.

The results of this particular test showed that, contrary to the authors' expectations, there was no observable difference, either in the voltage, or in the wave-forms of the voltage and current at the three points. The middle point was at the junction of Cables Nos. 10 and 11.

The current, of course, had different values at the three points, but whether it and the watts were in proportion to the equivalent length of cable cannot be stated with certainty, as the cables are of different types and sizes; the main point, however, is that there is no change in the voltage at the ends of the cable or in the shapes and relative phases of the voltage and current waves.

This experiment was made under different conditions: (1) with the cable open-circuited at the far end, and (2) with a small non-inductive load at the end. The results were the same in both cases except for a very slight reduction in the "kinks" in the voltage curves in the latter case and a slight shifting of the current wave owing to the higher power-factor.

The result is the more remarkable as it is the generally accepted view that in all long cables there is a rise of pressure due to the capacity; and, under certain conditions, this does undoubtedly take place. In all probability a variation of frequency would have produced the result expected.



nd watts.

It is unnecessary to show the curves obtained at the three points, as they are all practically alike.

The actual readings obtained are given in Table No. IV A.

TABLE No. IV A.

VARIATION OF CURRENT AND VOLTS ALONG CABLE.

		Volts.	Current.	Volt Amperes.	Watts by Oscillograph.
Cable on open Circuit.	Point A (near end)	2,000	6·08	12,160	901
	Point B (middle)	2,000	3·97	7,940	—
	Point C (far end)	2,000	0	0	0
Small load at end.	Point A	2,000	5·65	11,300	—
	Point B	2,000	3·75	7,500	—
	Point C	2,000	0·64	1,280	—

A wattmeter was not used in this experiment, and the oscillograph curves for the first reading only have been worked out.

The current and voltage curves in the last case are identical.

In addition to the above experiments, it was sought to confirm the results by the motor alternator method. The connections of the D.C. motor were as shown in Diagram No. V., the current being measured

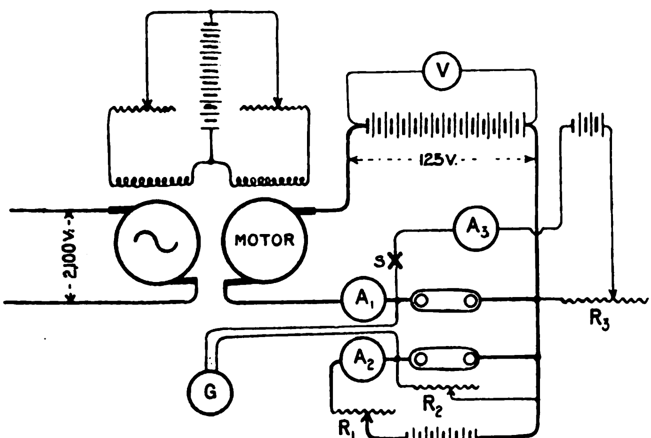


DIAGRAM No. V.

by a very sensitive differential method, which is clearly shown in the diagram. The galvanometer was calibrated by adding a small known current to the motor current and noting the scale deflection; the scale was a proportional one.

Whilst this method was applicable to the V.B. cable, giving the watts

taken by the cable rather lower than the result obtained by the other methods, it was found that when the jute cables were switched on less current was taken by the motor than before, no doubt owing to the efficiency of the alternator being improved by the alteration in wave-form. This does not include the increase of efficiency due to the reduced exciting current, as the exciting current was separately measured.

This objection could probably be got over by adding an inductive load at the same time as the cable, and adjusting it until the wave-form of the alternator was of equivalent shape. This could be proved by either taking oscillograph waves of the potential, or preferably by connecting up a condenser (another cable might be used for the purpose) and adjusting the inductive load until the current flowing into the condenser was the same as without the cable under test. The inductive load would be produced by an air core choker, and could be calculated and deducted from the total increase in power taken by the motor. Owing to lack of time, no definite results were obtained by this method. The motor alternator experiments are of value, however, in showing the great difference between the V.B. cable and the others.

The improvement in efficiency, apart from the reduction in exciting energy, caused by connecting circuits having capacity is a factor to be reckoned with when condemning the wastefulness of high-pressure cables.

TABLE No. V.

EFFECT OF CAPACITY ON EXCITING CURRENT.

	Voltage on Cable.	Exciting Current without Cable.	Exciting Current with Cable.	Watts saved in Excitation.	Approx. Watts in Cable (Paper)
A	10,000	5·8	2·5	426	2,000
	5,000	5·8	4·7	142	500
	2,000	5·8	5·4	52	80
B	10,000	17·5	13·2	555	2,000
	5,000	17·5	16·0	193	500
	2,000	17·5	17·2	39	80

A—30 K.W. Alternator. B—120 K.W. Alternator.

NOTE:—In addition, there is a further improvement in the efficiency of the Alternator, due to the effect of the altered wave form on the armature losses.

Table No. V. gives the reduction in excitation energy in various cases, and it will be noticed that the saving is quite comparable with the loss by dielectric hysteresis; so that beyond the objection to running a larger generator than is required to supply the actual watts consumed, there is really no great loss due to the use of high-tension cables, at any rate at 2,000 volts. In the summary, however, dielectric

hysteresis losses are included, as exciting energy is not considered in this paper.

The effect of variation of voltage is shown in experiments No. 15–20. It will be seen that with the particular form of wave applied the current increases rather more rapidly than the voltage, and the watts rather more rapidly than the voltage squared. This, of course, means that with very high voltages the watts absorbed may be a formidable quantity; but at the same time it must be remembered that as the voltage increases, so does the thickness of the dielectric. The capacity is therefore less, and, assuming no resonance, the cable volt-amperes and the watts absorbed will by no means increase as the voltage squared.

Some experiments were made on the effect of frequency, and the power-factor does not seem to be largely altered. As, however, there was some doubt as to the accuracy of the instruments employed in these tests, the figures are not here recorded.

The effect of load on the cable on this loss has not been satisfactorily investigated. It implies taking the difference of two very large quantities, compared with the loss, and is therefore not susceptible of much accuracy. In any case, the time during which the feeders in a lighting station are loaded is so small a fraction of the whole time they are running that the difference in the total result cannot be large.

Taking a comprehensive view of the above results, there appears to be no doubt that in the case of the V.B. insulated cable, No. 7, the power-factor is of the order of 0·12, that of the jute-insulated cables about 0·025, and of the paper-insulated cables something of the order of 0·032 and 0·08 respectively for Nos. 10 and 11; the first three results are fairly consistent with all the statements made in the discussion on Mr. Mordey's paper. The V.B. cable appears to be an exceptionally bad cable from this point of view, and the 5,000-volt paper cables appear to have a larger dielectric hysteresis loss than the jute cables.[1]

It is noteworthy that the cable which shows an abnormally high power-factor, viz., No. 7, is laid in an iron trough with iron cover.

It is possible that this iron trough, completely surrounding the cable, accounts to some extent for the high power-factor.

Where the cable is in an iron trough with a tile cover, as in the case of Nos. 10 and 11, the power-factor is also higher than would be expected from the type of cable. All the cables in Exp. 12 have the outers of slightly larger sectional area than the inners—roughly, 5 per cent. to 10 per cent. larger.

The fact that an external field exists round these cables is proved by the humming noise produced in the telephones connected to pilot wires

[1] The thickness of the dielectric between conductors of cables No. 7, 10, 11, and 13 is 0·28 in. The thickness over the outer is 0·10 in., except for No. 7, in which it is 0·25 in.

The iron trough in which the cables are laid is approximately 3½ in. by 3½ in. outside and ¼ in. thick.

Cable No. 4 is armoured with steel tape, but the thickness is only about $\frac{1}{32}$ in., and the outer and inner conductors are of the same section.

The capacity of the V.B. insulated cable is abnormally high, being over hree times that of a similar paper cable.

laid parallel and close to the cables. That this noise is not due to leakage entirely is shown by the fact that it is slight during times of no load, and very loud at times of heavy loads. Public telephone cables along the same route, but further away from the lighting cables, are not appreciably affected.

Taking the values given above, the total hysteresis loss in the Croydon system of mains comes out at about 17,000 units per annum, and is approximately equally divided between the four quarters. This is not so large a loss that it is worth while shutting down feeders for the period of light load to reduce it considering the risks involved in so doing. It is most important, however, to decide on a dielectric which will not give an abnormal loss, as in the case of Cable No. 7.

Transformer Losses.

The next point to be considered—and it is one of more importance than losses in the cable dielectrics—is that of transformer losses in an alternating current supply.

TABLE No. VI.

Transformer Losses.

Maximum Load supplied	1,250 k.w.
Maximum Tranformer k.w. in use	1,790
Minimum Transformer k.w. in use	920

(a) Total losses during time of heavy load	88,800	units per ann.
(b) Total losses during time of light load...	31,200	do.
(c) Total loss during day load	53,200	do.
Total losses per annum ...	173,200	units.

Note:	June Quarter.	September and March Quarters.	December Quarter.
Period (a) is as follows	8 p.m. to 12 midnight.	5 p.m. to 12 midnight.	2.30 p.m. to 12 midnight.
„ (b) „	12 midnight to 3 a.m.	12 midnight to 5 a.m.	12 midnight to 2.30 p.m.
„ (c) „	3 a.m. to 8 p.m.	5 a.m. to 5 p.m.	—

Table VI. gives the annual losses in the transformers necessary to deal with 1,250 k.w. output at the Croydon station. These transformers are placed in 26 sub-stations scattered over the district, and the total number of 56 of 1,790 k.w. total capacity is made up of :—

2 — 100 k.w.
19 — 50 k.w.
26 — 20 k.w.
3 — 27 k.w.
6 smaller sizes.

These are all in use at times of full load, and the number does not include spares. The loss is cut down as far as possible by switching off transformers not required for load. An attendant frequently visits the sub-stations for this purpose.

Notwithstanding this method of securing economical working, the aggregate losses are very large.

If all the transformers were kept on continually, the additional core losses would amount to 40,000 units at least per annum.

As an attendant must in any case visit the sub-stations, the saving by this method of working is very considerable.

The losses given in the table are as nearly as possible the average losses in ordinary working. The core loss in a particular 100 k.w. transformer, however, was 979 watts as minimum, with an applied voltage wave as shown on Curve No. 19, Sheet B, and 1,078 watts as maximum, with a wave as shown on Curve No. 8, Sheet C.

As this difference is so considerable, it was of interest to investigate the variations of wave-form occurring in ordinary working throughout the twenty-four hours. The results obtained are most striking, and very different to what were expected.

The curves obtained serve to emphasise what is often not fully realised, namely, that the wave-form obtained from any given alternator is almost as largely dependent on the kind of load it is called upon to carry as upon the design of the alternator. The curves were traced on a Duddell's oscillograph, and the main connections made to obtain them were as shown in Diagram No. VI., and were such as not to alter the normal running conditions to any appreciable extent.

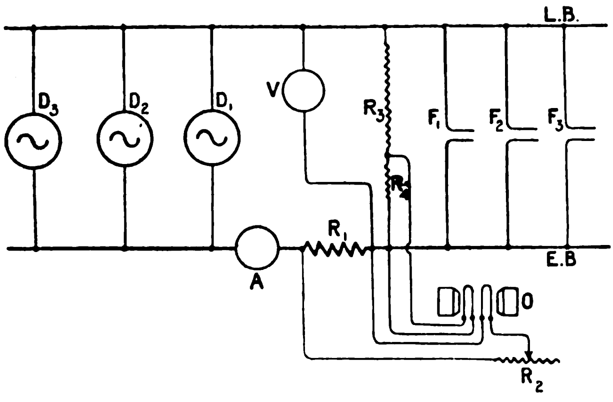


DIAGRAM NO VI.

LB is the live bus-bar and EB the earthed bar, the system of supply being 2,000 volts with one pole earthed. D1, D2, D3 are the alternators; F1, F2, F3 are the feeders; R1 is a non-inductive shunt carrying the whole current, and R3 and R4 are non-inductive resistances used as a potential divider to reduce the voltage from 2,000 across the bus-bars to the necessary 2 volts on the oscillograph; it consisted of a bank of

lamps with a small non-inductive resistance, R4 in series with it, across which the oscillograph voltage strip was connected; R1 consisted of brass condenser tubes arranged non-inductively, and tested for absence of self-induction. The height of the current waves was adjusted by altering the value of the shunt, and also by means of an adjustable resistance R2, in series with the oscillograph current coil.

The curves are sensibly correct in shape, but there may be slight errors due to their having been twice traced. There is also noticeable a slight difference in the horizontal width of the two half periods, due, no doubt, to a slight want of uniformity in the rotation of the mirror of the instrument. This error can, however, be allowed for.

TABLE No. VII.

Variation of Wave Form during 24 Hours.

No. of Curve, Sheet A.	Time.	R.M.S. Values.		Machines Running.	Remarks.
		Bus-bar Volts.	Total amperes		
	P.M.				
1	3.40	2,090	58	5	Transformers all on.
3	4.10	2,090	90	5, 7	
3	4.15	2,090	110	5, 7	
4	4.30	2,090	210	4, 5, 7	
5	4.45	2,100	350	1, 4, 5, 7	Some arcs on.
6	5.5	2,100	505	1, 2, 4, 5, 7	All arcs on (150 amps. for arcs.)
7	5.40	2,110	534	1, 2, 3, 4, 5, 7	
8	6.50	2,110	558	1, 2, 3, 4, 5, 7	Maximum load.
9	9.5	2,100	340	4, 5, 7	
10	9.15	2,100	310	5, 7	Some transformers off.
11	11.5	2,100	215	5, 7	
12	11.35	2,100	170	7	
	A.M.				
13	12.30	2,080	124	3, 4	H.N. arcs off.
14	2.10	2,070	118	3, 4	1 Transformer in each Substation on only.
15	4.50	2,070	103	3, 4	
16	6.3	2,070	114	3, 4	
17	7.15	2,070	130	3, 4	Some A.N. arcs. off.
18	8.4	2,070	63	3, 4	All arcs off.
19	8.25	2,070	43	2	
20	8.45	2,070	32	2	

N.B.—The P.D. waves are all to the same scale, but the current waves are to different scales.

Sheet A gives the curves obtained on January 20th, 1902, and Table VII. is the key to the reference numbers. Sheet B gives the curves obtained on July 26th of the same year, and Table VIII. is the corresponding key. Sheet C gives the voltage wave-forms of the various alternators running light, and also some miscellaneous waves, and

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No. of Curve, Sheet A.	T
	P
1	[illegible]
3	[illegible]
3	[illegible]
4	[illegible]
5	[illegible]
6	[illegible]
7	[illegible]
8	[illegible]
9	[illegible]
10	[illegible]
11	1
12	1
	[illegible]
13	1
14	[illegible]
15	[illegible]
16	[illegible]
17	[illegible]
18	[illegible]
19	[illegible]
20	[illegible]

N.B.—
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TABLE No. VIII.

Variation of Wave Form during 24 Hours.

No. of Curve, Sheet B.	Time.	Bus-bar Volts.	Total Amps.	Machines Running.	Remarks.
1	6.50	2,070	32	7	All transformers on. 5,000 volt cable on load.
2	7.25	2,075	70	7	
3	7.50	2,080	140	6, 7	
4	8.12	2,100	260	5, 6, 7	All arcs on.
5	8.58	2,115	510	5, 6, 7	Maximum load.
6	10.50	2,100	310	5, 7	
7	11.30	2,100	200	7	
8	12 mdnt	2,090	110	7	H.N. arcs off.
9	12.15	2,090	110	4, 7	
10	1 a.m.	2,090	100	4	Only a few transformers on.
11	2.55	2,060	85	4	
12	3.32	2,060	30	4	Some arcs off.
13	4.5	2,050	26	3	All arcs off.
14	7.5	2,060	18	3	5,000 volt cable off.
15	7.10	2.060	26	3	" " " on.
16	10.50	2,060	26	1, 3	" " " "
17	11.20	2,060	26	1	" " " "
18	4.15	2,060	24	1	5,000 volt cable on and Rect. Arcs Circuit.
*19	6.40	2,060	30	1	5,000 volt cable and all transformers on.
20	7.30	2,060	30	7	" " " "

* This current curve was actually taken before No. 1, and the volt curve interpolated from previous records.

N.B.—The D.P.-waves are all to the same scale, but the current waves are to different scales.

Table IX. is the key to this sheet. The sine waves equivalent to the various voltage waves are shown by dotted lines. The normal periodicity is 60 per second.

The curves have not been taken at regular intervals of time, but only when, owing to some alteration in the kind or magnitude of the load, there was likely to be a change in the shapes of the waves.

The alternators are all of the iron core, slot wound, revolving armature type, with large percentage regulation. Nos. 1 to 5 were designed to be short-circuited with impunity. They are direct-coupled to their engines and, under normal conditions, run perfectly in parallel at all loads.

On comparing the two sheets A and B, the first noticeable point is the remarkably peaked waves in B. The only difference was the addition of a feeder working at 5,000 volts and 3·6 miles long, a few other 2,000-volt and 200-volt cable extensions, and also No. 6 alternator.

The effect of this increased capacity is to totally alter the shape of the current waves and to appreciably alter the voltage waves.

TABLE No. IX.

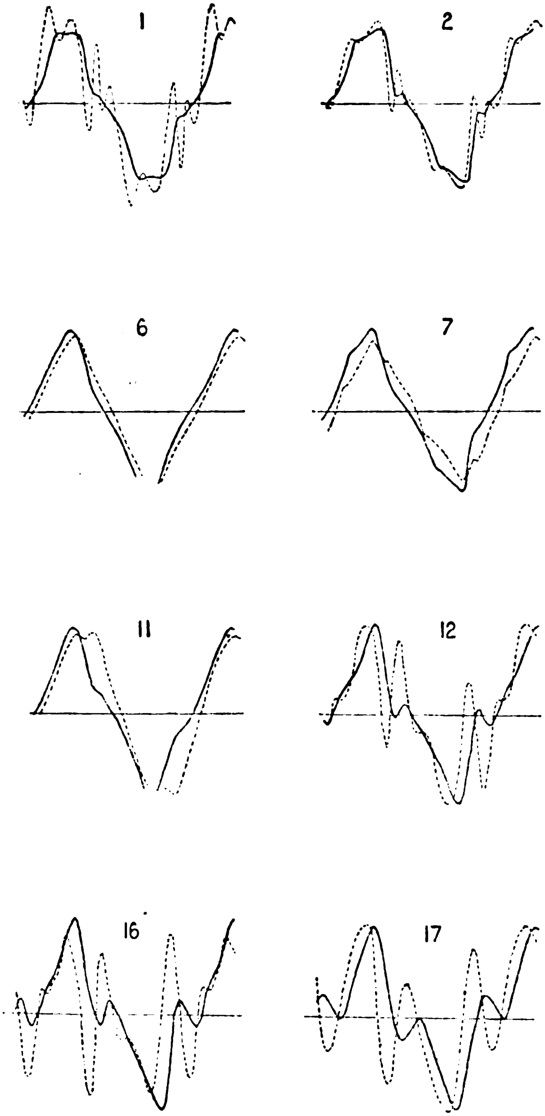
No. of Curve, Sheet C.	Description of Curve.	Alternator No.	R.M.S. Volts.
1	P.D. Curve 30 k.w. Motor-driven Alternator running light	M.A.	2,060
2	,, ,, 120 k.w. Alternator running light	1	,,
3	,, ,, ,, ,, ,, ,, ,,	3	,,
4	,, ,, ,, ,, ,, ,, ,,	3	,,
5	,, ,, 250 ,, ,, ,, ,,	4	,
6	,, ,, ,, ,, ,, ,, ,,	5	,,
7	,, ,, 500 ,, ,, ,, ,,	6	,,
8	, ,, ,, ,, ,, ,, ,,	7	,,
9	P.D. Curves of Rectifier, Applied and Rectified volts, Rectifier running on small Transformer loaded	...	Applied: 2,080 Rectified: 16·8
10	P.D. Curve 500 k.w. Alternator running light	6	2,090
11	,, ,, ,, ,, ,, ,, ,,	7	,,
12	,, ,, Nos. 6 and 7 Alternators in parallel; synchronising current curve dotted	...	2,090 Current about 15 amps.
13	,, ,, 30 k.w. Alternator running light at 15·3 $\sim$, on 5,000 volt cable through 200 volts — 2,000 volt transformer	...	2,045
14	P.D. Curve of 30 k.w. Alternator loaded to 16 k.w. running at 60 $\sim$, on 5,000 volt cable alone	...	2,050
15	Current Curve, 30 k.w. Alternator light at 30 $\sim$, on 5,000 volt cable	...	Current: 0·58 amp.
16	P.D. Curves of Primary and Secondary volts on 2,000 — 5,000 volt 100 k.w. transformer	...	Primary: 2,100 Secondary: 5,250

NOTE:—All the Alternators have slotted iron cores, revolving armatures and laminated poles.

It is interesting to notice how, with the load consisting chiefly of cables, the current is leading. As the load increases, the current and voltage waves approach each other in phase and the irregularities are smoothed out. Late at night when the load is mostly arc-lighting, the current lags. Some very remarkable effects are produced by the flat-topped wave of No. 7 alternator, as shown in Curve No. 12, Sheet A, and Curve Nos. 7, 8 and 9, Sheet B.

On Sheet C the additional curves are exceptional, and show what remarkable effects may be produced by suitable combinations of capacity and inductance. These were obtained with the ordinary plant of the station in the course of some miscellaneous experiments, and they point out the necessity of not allowing abnormal conditions to arise in working, or the safety of the cables and transformers may be seriously

VARIATION OF VOLTAGE AND CU



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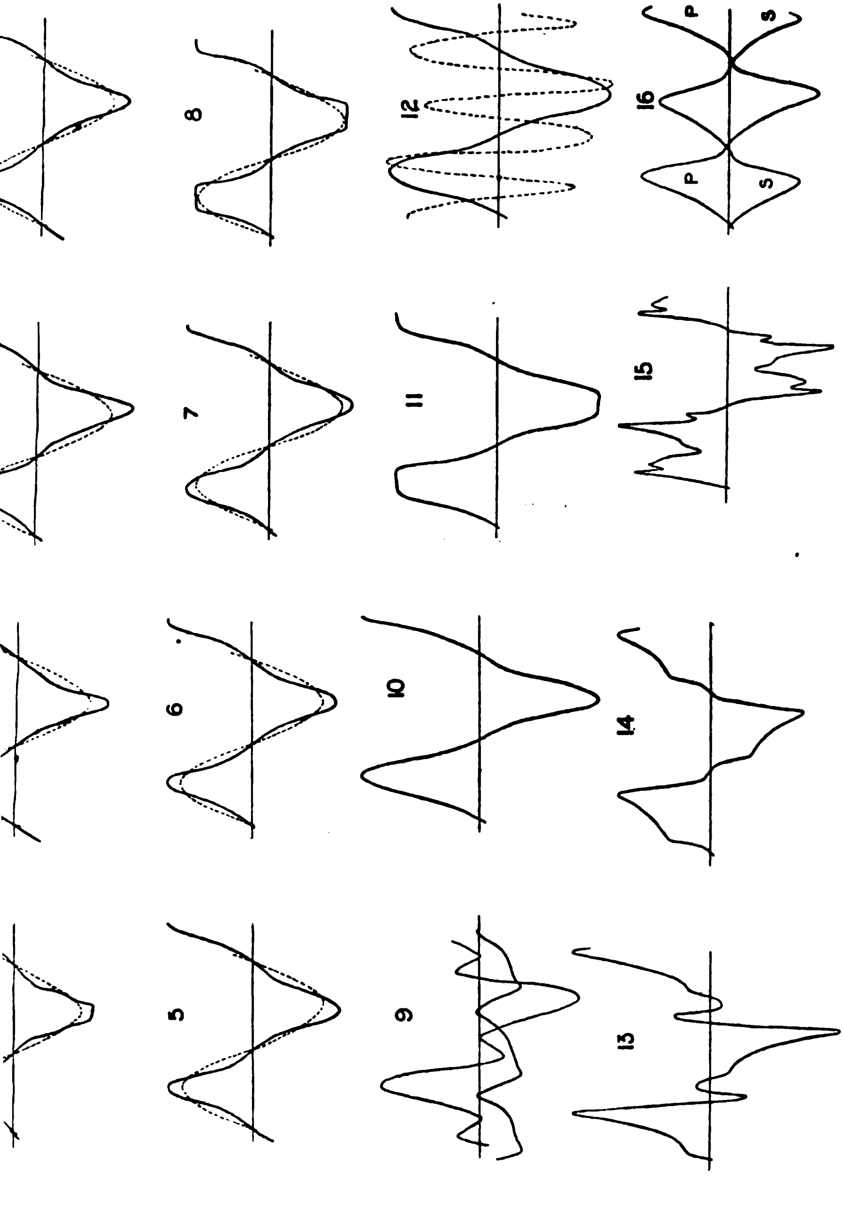
VOLTAGE WAVE FORMS OF ALTERNATORS, ETC.



SHEET C (SEE TABLE NO. IX.).

endangered. Curves Nos. 10, 11, and 12 on this sheet show respectively the voltage curves of alternators Nos. 6 and 7 running singly and also in parallel. The dotted curve in No. 12 represents the synchronising current flowing between the two machines, its R.M.S. value being about 15 amperes. The voltage curve of the two in parallel is practically the mean of the separate curves. In connection with the general question of parallel running of alternators, the following result is interesting: On one occasion an attempt was made, for convenience in practical working, to join up two machines in parallel through two concentric cables, each about four miles long. Under these conditions the machines would not keep in phase at all, although under normal conditions they ran perfectly together.

Meter Losses.

The question of meter losses now remains to be dealt with.

There are in use in the district being considered rather more than 1,200 meters, and the same number of Wright's Demand Indicators. About 1,000 of these meters are Thomson meters, and the rest of the Westinghouse Co's manufacture.

The shunt losses are by far the most serious, as these go on continuously, and they amount to a total of 37,400 units per annum.

As is well known, the shunt loss of a Thomson meter is rather high: the Westinghouse meter, however, only takes about 1 watt in the shunt.

The series coil losses, worked out from the load curves for private lighting, only reach a total of 1,350 units per annum for both meters and demand indicators. This low figure is due to the short hours the meters have any appreciable load on them, and to the fact that in the majority of cases the meter is never run at its rated full load.

In fact, the total amperage of meters installed is about 3·6 times the maximum current used for private lighting.

It is evident that a large economy could be effected by abolishing the shunts altogether and using ampere-hour meters. The only difficulty is the variation of the consumers' pressure from the supply standard.

In very few cases, however, is the variation more than the limit of inaccuracy allowed in the meters, and on the average the standard pressure will be very nearly kept to.

Using an energy meter, the consumer who gets a good pressure pays a little more for his ampere-hours than he otherwise would, and is well satisfied. In the case of an ampere-hour meter, the consumer with a bad pressure pays for rather more units than he uses, but he will not notice the difference in his bill, and he will complain of the bad light in any case.

There are further advantages in using ampere-hour meters, viz., cheapness, ease of installing and less risk of breakdown.

The large loss in the shunts given above is due, of course, to the particular type of meter in use, but the Thomson meter is not the worst in this respect, though it is far from being the best.

So far, the losses have been enumerated without much reference to

TABLE No. X.

SUMMARY OF LOSSES.

	Quarters.								Year.		Percentage of Units Generated.	Percentage of Units sent out.
	May, June, July.		Aug., Sept., October.		Nov., Dec., January.		Feb., March, April.					
Losses in Switchboards and Connections ...	...	600	...	2,000	...	5,000	...	2,400	...	10,000	0·51	0·54
Cable Losses:												
H.T. { Leakage and Dielectric Hysteresis ...	4,100	...	4,100	...	4,100	...	4,100	...	16,400	...	...	...
H.T. { C^2R	3,400	...	10,600	...	22,200	...	11,000	...	47,200	...	...	...
Cable Losses:												
L.T. { Leakage and Dielectric Hysteresis ...	500	...	500	...	500	...	500	...	2,000	...	...	...
L.T. { C^2R	6,800	...	16,500	...	25,400	...	17,500	...	66,200	...	...	...
C^2R Loss in H.T. and L.T. Arc Cables	4,640	...	8,710	...	13,820	..	10,030	...	37,200	...	...	...
Total Cable Losses	...	19,440	...	40,410	...	66,020	...	43,130	...	169,000	8·7	9·2
Transformer Losses:—												
Core Loss	26,000	...	27,000	...	20,000	...	27,500	...	100,500	...	...	...
Copper Loss	9,500	...	17,400	...	19,400	...	17,400	...	63,700	...	...	...
Total Transformer Losses	...	35,500	...	44,400	...	48,400	...	44,900	...	173,200	8·9	9·4
Meter Losses:—												
C^2R	60	...	370	...	850	...	470	...	1,750	...	...	...
Shunt	12,500	...	12,800	...	13,400	...	12,800	...	51,500	...	...	...
Total Meter Losses	...	12,560	...	13,170	...	14,250	...	13,270	...	53,250	2·7	2·9
Total Losses	...	68,100	...	99,980	...	133,670	...	103,700	...	405,450	20·8	22·0
Per cent. of Units sent out	...	33·4	...	24·8	...	18·5	...	20·5	...	22·0	...	...
Units Generated	...	223,000	...	423,000	...	764,000	...	538,000	...	1,948,000	100	...
Units sent out...	...	204,000	...	403,000	...	724,000	...	506,000	...	1,837,000	94·4	100
Units sold (*a*)	...	135,900	...	303,020	...	590,330	...	402,300	...	1,431,550	73·4	78·0
Units sold (*b*). Sum of Consumers' Meter Readings	...	139,000	...	344,000	...	638,000	...	381,000	...	1,502,000	77·0	81·7
Per cent. Units sold to Units generated... ...	...	61	...	72	...	77	...	75	...	{ 73·4 (*a*) { 77·0 (*b*)	...	...

DISTRIBUTION LOSSES.

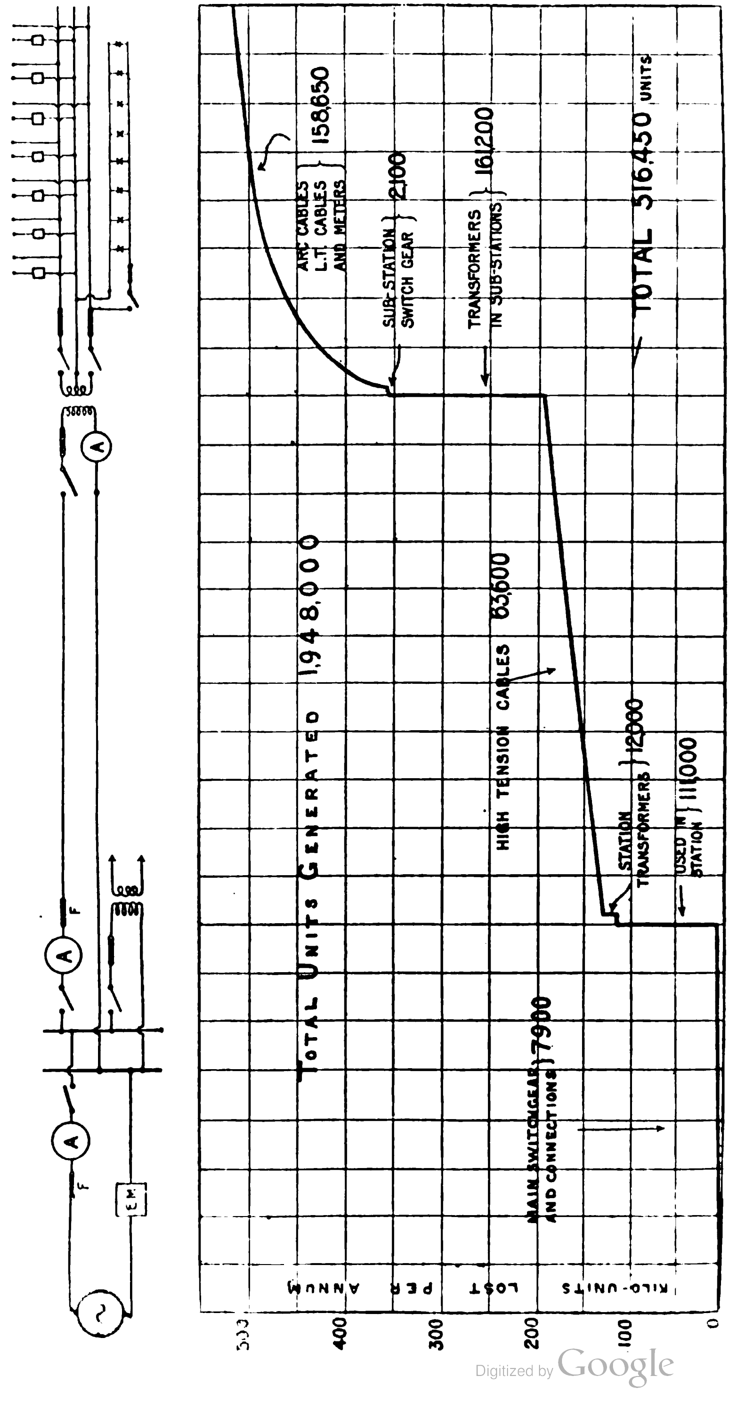


DIAGRAM No. VII.

the total output of the station. In Table No. X. the whole of the losses are summarised and expressed as percentages of the total units generated and the total units sold.

Diagram No. VII. is a graphic representation of the losses as they occur in the system.

It will be seen from the Table that the calculated loss is 22 per cent. of the units sent out of the station. From the actual sum of the consumers' meter readings, however, the loss appears to be only 18·4 per cent. This difference of 3·6 per cent. is no doubt partly due to a rather liberal estimate of the losses in some cases; numerous approximations are required, and it is impossible to calculate the losses with great accuracy. It may also be partly due to small errors in the meters. The total units generated depend on the average accuracy of seven meters, whilst the total sold depends on 1,200—a difference of 2 or 3 per cent. may thus easily occur.

There is a further side to the question which, however, as it hardly comes within the scope of this paper, will be briefly dealt with. It may be economical to waste energy as long as interest has to be paid on borrowed money. It is, of course, possible to reduce C^2R losses at any rate to a negligible amount, by putting in enough copper, but it is not economical to do so.

It is the duty of the engineer to design a system which shall give the best result for the least annual expenditure; he must avoid losses in transmission up to the point where the expense of avoiding them becomes greater than the cost of the energy lost. A case illustrating the comparative advantages of two alternative schemes is the following:—

A certain portion of the district considered in this paper was originally supplied with alternating current from four sub-stations, fed at 2,000 volts. After a few years the load became much heavier than at first, and it was found both more economical and advisable for other reasons to change the supply to direct current without transformation, using the same low-tension mains, instead of adding to the section of the existing cables. The total losses per annum under the old system amounted to 49,100 units. With the new system for the same load the losses are 40,300 per annum, so that there is a saving of 8,800 units in favour of the direct-current supply, and the cost of the alteration was considerably less than that of the other alternative.

The average distance of these sub-stations from the generating station is 1,290 yards, or about three-quarters of a mile, and the maximum load is about 400 k.w. in all.

With regard to the means for reducing the losses in general to a minimum, the methods to be adopted have been mentioned under the various sections of this paper, but they may be summarised here. Primarily good design is necessary; after that, care must be taken to remove useless causes of waste during times of light load.

The cure for waste of energy in switchboards and station connections is simple design, good workmanship, and choice of suitable positions. Cable losses may be reduced, assuming suitable dielectrics have been selected, by switching off high-tension cables not required for

load, but, as in most cases the saving by doing this is small, the extra risk of cable breakdowns more than counterbalances it.

C^2R losses in the low-tension system may be cut down by interconnecting the network so as to use all the copper laid down, to the best advantage. Fuses between the various sections must be relied on in case of breakdown if this is done.

Transformer losses during light loads are, of course, reduced by switching out transformers which are not necessary. This practice is not, in the opinion of the authors, detrimental to the safety of a well-made transformer. It may certainly pay in some cases to scrap transformers of an old and wasteful type, rather than to use them until they are worn out. It may be worth while to either artificially alter the wave shape during the day, or to run machines with a peaked wave in order to reduce the core loss.

It is hardly admissible to alter the frequency unless no motors whatever are in use.

To remove the largest source of loss in meters, shunts should be abolished, as discussed in the section on meters.

Although this paper deals with the Croydon system of distribution, the arguments hold good generally, whether the supply is by means of alternating or direct current.

The question of losses in tramways or power schemes is considerably modified, however, by the altered conditions of working.

There are in such cases only a few hours of light load instead of the larger part of the day, and as the losses will be practically all C^2R loss in the cables, much heavier copper must be put in to secure the most economical working.

The losses detailed in this paper are incurred in a system which is indisputably, on the whole, well arranged and economically worked. The district has the disadvantage of being a very extended one, so that the number of consumers per mile of mains is small. This accounts for part of the large C^2R losses, but even so the remainder is of very considerable magnitude, and there must be many supply systems working under worse conditions.

The engineers of these systems will, however, probably feel hurt if they are told that they are guilty of slowly, but surely, throwing away the coal resources of the Empire, and that they are, therefore, neither serving their profession or their country in the highest degree.

In conclusion, the authors wish to heartily thank Mr. Minshall for his help and many suggestions, and also to thank his successors at Croydon for their kind permission to complete the necessary experiments and to publish these results. Several members of their staff have also merited thanks for much valuable assistance and unflagging interest in the experimental work. A tribute is due to Mr. Duddell for having placed on the market so beautiful an instrument as his oscillograph; but for the interest attached to the use of this instrument, this paper would not have been written.

INDEX TO TABLES.

INDEX TO DIAGRAMS.

INDEX TO CURVES.

Mr. M. B. Field then read an abstract of his paper, entitled "A Study of the Phenomenon of Resonance in Electric Circuits by the Aid of Oscillograms" (see above, page 647), read before the Glasgow Local Section.

President.

The PRESIDENT: I will not occupy the time of the Institution in complimenting the authors of these papers; everybody who has looked at them knows how much we are indebted to them for their labours.

Mr. Leonard Andrews.

Mr. LEONARD ANDREWS: Whilst I have been very interested in both the papers we have listened to, I have only a few remarks to make on the first one. This question of distribution-losses has been troubling us at Hastings for some years. Until two years ago our losses in the summer months amounted to about 50 per cent. of the units generated. Various alterations were made to reduce these losses, and last year, during the months of June and July, they only averaged 27·3 per cent. of the units generated. To roughly locate these remaining losses we fixed meters in the sub-stations between the low-tension transformer 'bus-bars and the distributing 'bus-bars. By this means we were able to compare the units generated, the units turned out from the sub-stations, and the units metered to consumers. The losses in the high-tension feeders and transformers during the two months referred to amounted to 16·8 per cent. of the units generated, and the losses in the low-tension mains and consumers' meters to 10·5 per cent., thus making the total distribution-losses 27·3 per cent. of the units generated. It appears from Table 10 of the authors' paper that the corresponding losses at Croydon amounted respectively to 20·8 per cent., 9·8 per cent., and 30·8 per cent. of the units generated during the summer months. At Hastings the whole of the high-tension feeders and transformers are cut off shorly after 11 p.m., and are left disconnected until sunset the following day. During the hours of light load the supply is maintained through the low-tension network alone, from one sub-station adjoining the works. On page 16 of their paper the authors suggest that the dielectric hysteresis losses are insufficient to make it worth while to cut off the high-tension feeders during the hours of light load, when the risks involved in doing so are considered. They recommend, however, that some of the transformers should be switched off to reduce the transformer-losses. They appear to have overlooked the fact that the risk incurred in switching transformers on and off is probably quite as great as switching feeders on and off, added to which it is a risk which cannot be so easily dealt with. If the feeders and transformers are switched off simultaneously, as is done at Hastings, some simple cable-charging device can be used for this purpose, and thus the rise of pressure in both feeders and transformers can be prevented. That rises of pressure do often occur when a transformer is excited, either from the low-tension or high-tension side, may be seen by the aid of an oscillograph or by connecting a spark gap across the primary terminals. If the spark-gap is adjusted to just not break down at double the normal working pressure of the primary of the transformers, a spark will jump across the gap at the moment of connecting the secondary windings to a low-tension source at normal

pressure. Quite apart from the reduction of dielectric hysteresis losses effected by switching off feeders during the hours of light load, there is a great advantage in having the whole of the high-tension system dead in the daytime for alterations or testing. The variation in the shape of the curves that the authors have shown is very interesting. We have also noticed that we get a very different shaped curve on light load to what we get on full load, though this difference only appears to be noticeable on iron-cored machines. The authors refer to the fact that they have found that, under certain conditions, the current curve lags behind the E.M.F. curve. I have been rather surprised to notice that at Hastings under no conditions do we get a lagging current. Even when the load is made up of 50 per cent. of arc lamps and magnetising current the current still appears to lead. This is probably due to the fact that there are several miles of vulcanised rubber cable connected to the system. The authors suggest that meter losses might be reduced by doing away with the shunt-windings in meters. I think it would be found that to do this would tend to introduce another, and a much more serious, source of loss, namely, that due to the meters failing to start on light load. With very small meters, that are only expected to carry a maximum load of two or three amperes, this difficulty does not exist, and it is probable that with these meters the saving effected by doing away with the shunt-windings would more than counterbalance any loss due to consumers being supplied at a pressure two or three per cent. above the declared pressure. Larger meters can, however, only be relied upon to start on light loads if they are constructed with shunt-windings. We effected a very considerable saving a few years ago by taking out the whole of our ampere-hour meters and replacing them by watt-meters, in spite of the losses introduced due to the shunt-windings of the latter. Mr. Leonard Andrews.

Major P. CARDEW: I will not detain you very long, because, although I made three attempts during the last week to read these very interesting papers, they were always stolen from me, and I have not been able to get through them. The point that forcibly occurs to me, looking back to the time when we were settling regulations, is how lucky it was that we stipulated that all cables were to be tested with twice the working pressure with one hour, seeing what a tremendous amount of increase of pressure you get from these exaggerated ripples. If that is carried out, I think the cables ought to stand all that they are likely to be subjected to, even from the amount of resonance that may take place. There is no doubt that the charging of a cable is, in all respects, very much like dealing with a live load on a bridge. I think a practical way to look at it is that the cable must be strong enough to stand the extra stress which comes upon it. At the same time, it occurs to me that, with a view to diminishing to some extent the danger to cables on systems with high pressures, something might be done in modifying the switching arrangements —the switching on and off. As far as I have read the discussion on this paper, and on all other papers, it is always taken that the absolute charge—the contact—is an instantaneous thing; but when we see what a lot may happen during one period of a fiftieth of a Major Cardew.

Major Cardew.

second it occurs to me that the absolute contact is not by any means instantaneous, and that the cable is really eased up at high pressures—pressures of 5,000 volts and upwards—by the arc which takes place as the switch is closed. And, more than that, we must consider the effect of the closing switch as being to some extent an adjustable condenser, rapidly increasing its capacity and in series with the capacity of the cable. That being so, of course the voltage condensed on the moving contacts of the switch is continually diminishing as the charge increases; and, on the other hand, the voltage condensed across the cable is gradually increasing all that time. By some arrangement which will give more capacity effect to the switch as it closes, I think very considerable relief could be obtained.

The PRESIDENT announced that the scrutineers reported the following candidates to have been duly elected :—

Members.

Daniel Coyle.
Joseph Wilkinson.

Associate Members.

Rooke Ainsworth.
Edward Calvert.
Samuel McLean.
Charles Andrew Newton.
John Walter Parr.
Charles Norman Robinson.
Walter Stewart.
George Gordon Tomkins.

Associates.

Arthur Baker.
James Stephen Blackwell.
Joseph Boyce.
William John Charlton.
Thomas Dow Frew.
John Jamieson.
Thomas William Storey.

Students.

Charles Reed Allensby.
William George Herbert Cam.
Albert W. Deakin.
William Rowland Ding.
Thomas Ellis.
Reginald Woolton Fowler.
P. L. R. Fraser.
James Frederick Gay.
Alexander Lindsay Glegg.
Masanoske Hayashi.
Kenneth Horton.
William Howes.
Clarence Hambly Hughes.
Alfred James Munday.
Thomas George Partridge.
John G. Potts.
Morgan Howell Rees.
Alfred Ernest Scott.
Frederick Smith.
Richard Edward Wellard.

The Three Hundred and Ninety-first Ordinary General Meeting of the Institution was held at the Institution of Civil Engineers, Great George Street, Westminster, on Thursday evening, March 26, 1903—Mr. JAMES SWINBURNE, President, in the Chair.

The minutes of the Ordinary General Meeting held on March 12th were taken as read and signed by the President.

The names of new candidates for election into the Institution were taken as read, and it was ordered that these names should be suspended in the Library.

The following list of transfers was published as having been approved by the Council :—

From the class of Associate Members to that of Members—

Reginald Page Wilson.

From the class of Associates to that of Members—

Stephen Stewart Goodman.

From the class of Associates to that of Associate Members—

Leonard Breach.	Arthur Frederick Malyon Gatrill.
Edward Macgregor Duncan.	Thomas McGill.

Herbert James Read.

From the class of Students to that of Associates—

Percy Meares Crampton.
Robert Saunders Newton.
Richard Lloyd Pearson.

Messrs. F. Graham and A. G. Inrig were appointed scrutineers of the ballot for the election of new members.

The PRESIDENT: The Students have been working very hard, and have got up a large subscription in aid of the Building Fund. They have collected no less than £83 6s., and after deducting the various small expenses, there is a balance of £79 10s. 6d. to add to the Building Fund. I am sure the Institution would like me to read this letter :—

"*March* 26, 1903.

"DEAR MR. MCMILLAN,—I enclose the balance sheet (which is a copy of my own) of our Students' Subscription List to The Building Fund of the Institution of Electrical Engineers. This fund was opened on January 1st and closed on March 30th last, and through our efforts we have been able to collect, as you will see, a net amount of £79 10s. 6d. By a motion of the Committee, I am not to give you a list showing the amount subscribed by each student, but just a list of the names of those who have subscribed; this list I will send you, together with a cheque for the balance I have in hand, in the course of a day or so. I also

enclose a copy of the letter that was sent out, and hope these will reach you in time to be placed before the Council this evening. The total number of Students who have subscribed is 644, although included in this number are some Students who are studying electrical engineering, though not Student Members of the Institution. My Committee are extremely pleased with the result of this movement, as it shows that the Students recognise the desirability of a home for the Institution.

"Believe me,

"Very sincerely yours,

"HAROLD D. SYMONS."

Donations to the *Library* were announced as having been received since the last meeting from Messrs. C. Bright, C. Naud, and Whittaker & Co.; to the *Building Fund*, from Messrs. B. Balaji, S. Evershed, and J. F. Henderson; and to the *Benevolent Fund* from Mr. W. E. Russell, to whom the thanks of the meeting were duly accorded.

The PRESIDENT: I have to announce the result of a Special General Meeting of the members, held for the purpose of altering the Articles of Association. There were not many alterations, and I will just explain the principal ones. The first is to give the Council the power, which is given in most Societies, of removing at their discretion any one who is either a bankrupt, on the one hand, or on the other hand—the two things have nothing to do with each other—a felon. That is a Clause which is inserted in most Articles of Association. I would point out that it does not by any means indicate that supposing a man were unfortunately to become bankrupt he is to be expelled from the Institution, but supposing a man were a fraudulent bankrupt, or it was supposed that he was a fraudulent bankrupt, it might be very necessary to remove him; but unless there is some such rule as this the Council would not be able to do so without practically saying he was a fraudulent bankrupt, and that might lead the Institution into an action for slander, libel, or something of that sort. As the Article has been altered, in extreme cases it gives the Council power to take action. The next alteration is with regard to the Vice-presidents. Under the alteration two Vice-presidents retire every year. The idea is that it does not follow that every Vice-president should in the ordinary turn become President. It is rather difficult under the old rules to elect a member a Vice-president unless you desire to make him President also, and there are a great many people who would be very useful as Vice-presidents without necessarily being very well qualified to serve as President. It also gives us a bigger number to choose from. The arrangement is that in future two Vice-presidents will always retire, and the President must be chosen from some one who has been a Vice-president; so that a man who has once been a Vice-president is eligible for the Chair. By that means we will get a number of people, as it were, in stock to choose from, and it is felt that that will be better for the Institution. The only other alteration of any importance which I think I need mention is that the

Associate Members are now to have the power of voting with the Members in any important matter, such as altering the Articles of Association, or anything of that kind. The Council feel that the Associate Members and the Members only differ in degree, and that they ought to be one body. The last alteration is a matter of form, which, I believe, is legally unnecessary; it provides that every new member shall promise to agree to the rules of the Institution, and so on.

As I mentioned at our last meeting, it is very important that the Institution should have a President who should not only take charge of the Institution during the time of the International Telegraph Congress which is to be held in London, but should also be in the Chair early enough to make his arrangements for taking over the control of the Institution during the whole time. I sent in my resignation, as I said I would, and the Council have elected Mr. Gray to take the place of President. I can only say that I have the greatest pleasure in resigning in favour of Mr. Gray. Mr. Gray will now have time to organise the entertainments of the Congress in a way that I feel sure you will find will do great honour to the Institution. I have great pleasure in resigning in favour of Mr. Gray, and I will now ask him to take the Chair.

[Mr. Swinburne then vacated the Chair, which was taken by Mr. R. K. Gray.]

Mr. J. GAVEY: Gentlemen, before the new President addresses you, I should like, if you will allow me, to intervene with a few remarks. The post of President of this Institution confers high honour on the holder, for he is for the time being the head of our profession. It also entails very onerous labours, labours of which, perhaps, only those who are on the Council, or who have served on the Council, are really good judges. You are able to appreciate the able manner in which the past President has upheld the high traditions of his office in presiding over your meetings. I, as a member of the Council, can testify to the great business aptitude with which he has conducted the deliberations of the Council, and with which he has managed the affairs of your Institution. Gentlemen, great professional ability or great business acumen compel admiration, but there are other qualities which command esteem and regard; and personally I can say that your retiring President has, during his year of office, shown such an amount of tact and courtesy in dealing with the affairs of the Institution, that he leaves behind him a body of men, who, I venture to say, consider themselves his personal friends. If you want an illustration of the tact and courtesy with which he has dealt with his duties, I need only call your attention to the graceful and generous manner in which he has retired before the expiry of his period of office, in order that his successor may have the fullest opportunity of organising the reception of the International Telegraph Conference in the manner most satisfactory to himself and to the best advantage of the Institution. I have much pleasure in proposing a very hearty vote of thanks to the retiring President.

Mr. W. H. PATCHELL: Gentlemen, the duty which devolves upon

me to night should properly devolve upon one of the Vice-presidents, but they are unfortunately absent owing to the Dinner to Sir William White, which has called for the personal service of them all. Our past President—I am sorry to have to call him so so soon—ought to have been there also, and it is only another instance of the courtesy with which he has invariably treated us here that he has foregone so much of the dinner, although he hopes presently to get in for the ices. Mr. Gavey has told you something about our past President's handling of the Council, and you have seen for yourselves the way in which he has handled these meetings. As a specimen of his tact, I need only refer to the fact that he had hardly got into the Chair when he had to head the deputation to the Board of Trade, and I think the handling of that deputation was just a masterpiece of diplomacy. No words from me could give you any higher opinion of Mr. Swinburne than he has earned for himself. He is only a young man, and I hope we may live to see him serve us again when, instead of having an abbreviated year of office, I hope we may be able to give him a leap year.

The resolution was carried with acclamation.

Mr. J. SWINBURNE: Mr. President and gentlemen, it is very difficult indeed for a man to reply to such very kind speeches as I have heard to-night, and to reply after a vote of thanks has been carried in the way in which you have carried this one. I can only say that being your President is the greatest honour that can be conferred on any member of the profession. But in my case I have felt that it was not only a great honour but an immense pleasure. I have had nothing but pleasure throughout the time I have had the honour of being your President. I am very sorry to resign in one sense, and in another sense I am very glad indeed, because, though I have enjoyed my time very much, and everybody has treated me with the greatest kindness, I cannot help feeling that in Mr. Gray you have a more experienced man, a man who will be about the best President you possibly could have. I thank you, gentlemen.

The PRESIDENT (Mr. R. K. Gray) said: Gentlemen, before proceeding to the discussion of the papers that we have before us to-night, I desire to say, in as few words as possible, that I appreciate very much the honour which has been conferred upon me by the Council, and I sincerely hope I shall be able to follow the traditions of my predecessors in this Chair. I will not occupy your time any longer, except to tender you my best thanks for the very kind way in which you have received the announcement which Mr. Swinburne has made to you.

RESUMED DISCUSSION ON PAPERS ON "DISTRIBUTION LOSSES IN ELECTRIC SUPPLY SYSTEMS," BY A. D. CONSTABLE, A.M.I.E.E., AND E. FAWSSETT, A.I.E.E., AND "A STUDY OF THE PHENOMENON OF RESONANCE IN ELECTRIC CIRCUITS BY THE AID OF OSCILLOGRAMS," BY M. B. FIELD, M.I.E.E., A.M.I.C.E.

Mr. Minshall

Mr. T. H. MINSHALL: I think the peculiar value of these two papers which are before us to-night, dealing as they do with the

oscillograph, is not so much the accuracy of the results which are given, although many of those are very interesting, but the number of new suggestions which they make to men engaged in practical engineering. Mr. Constable's paper, together with the diagrams which are given, has come in a sense as a revelation to a great many station engineers. A good many of us did not realise, until the oscillograph was made a practical instrument, what extraordinary wave-forms we have to deal with; and when one sees some of the very peculiar shapes which are shown in some of the tables, more especially in Table No. 4, one is not at all surprised at almost any form of resonance effect or breaking-down effect which one hears of in actual practice. There are several points that occur to me which have not had much attention drawn to them before. One of those is the question of the enormous loss which goes on in all central stations. One does not realise that actually 25 per cent. of the total output of a station is, at the present time, lost. Of course it must be borne in mind that of that loss a great deal occurs at the top of the load, and that hence the cost of generation of those units must be taken as the maximum possible. Taking these units given in the paper, and allowing the average cost of generation of the total of 173,000 units, we get between £200 and £300 a year actually lost; if you can save them, or prevent them going in any way, it is all profit. I do not know that there are any other points that occur to me in connection with the first part of the paper. The dielectric hysteresis is the part which appeals to me as the most interesting, although possibly it is not the one of the greatest practical importance. This paper originated with some experiments that Mr. Constable made for me in connection with the discussion on Mr. Mordey's most interesting paper last year. Members may recollect that in that paper Mr. Mordey showed some results with a power-factor of the order of 0·1. The Institution at the time as a whole, I think, did not entirely agree with those figures, and we made some experiments at Croydon to see if such a thing were possible. It so happened that the experiments we conducted were not on a paper cable, but on a vulcanised bitumen cable, and we got results almost exactly agreeing with Mr. Mordey's. I do not pretend that anybody believed them; so we spent some time and trouble since then in attempting to produce the results by several methods. I think Mr. Constable shows here fairly conclusively that with a cable of this peculiar construction and material, it is quite possible to get a power-factor of the order of 0·1. As a matter of fact, when he comes to deal with jute cables and paper cables, of course then the results which he obtained are more in accordance with those which were obtained by so many investigators last year. There is no doubt, I think, that the ordinary power-factor of the ordinary paper cable is of the order of 0·01 or 0·02. I do not think it would be very much higher, although some of the jute cables seemed to go as high as 0·03, but I should think 3 per cent. is the maximum power-factor which is obtained from any of these cables in commercial use. Mr. Constable gives on page 713 a very interesting *résumé* of the various methods which are applicable to a measurement of this Mr. Minshall.

Mr. Minshall.

kind. It is very important indeed that one should clearly realise the great difficulty there is in conducting investigations into what he has called dielectric hysteresis. The five methods he has given here are all of them to a certain extent practical, provided that you have sufficient time and apparatus at your disposal. The first one certainly appears to be one of the best. When I was in America last year I discussed the matter at some length with Mr. Steinmetz and Mr. Berg, and they were of the opinion that they would use the one the authors used; but when I showed them some of the wave-forms in the diagrams on page 711, they agreed that it was not perhaps such a good method to use as they had previously thought. My own conclusion is that if it is not possible to use a calorimetric method, the only method on which one could really rely with bad wave-forms is No. 3, that is, the direct measurement of increased power necessary to drive an alternator when a cable is switched on. Of course at the first glance it appears as if the measurement to be made is so extremely minute that it is impossible to measure it; but a small motor alternator, carefully driven, with the supply at the direct-current end measured on a potentiometer, would enable one, on a long cable, to get results of very considerable accuracy. The difficulty is that the wave-form of the alternator itself, unless care be taken, gets altered during the experiment; that is to say, you may have practically a sine wave before you put the cable on, and then immediately you put it on you get one of the forms shown in Table 4. I know that Mr. Constable took very great efforts to get over that. He took a motor alternator and loaded it up with 30 kilowatts, and switched a cable on the losses in which added 1 kilowatt extra load, hoping thereby he would preserve the same wave-form as before. But he found it was impossible to be quite sure, and I am afraid the results he obtained from that are more or less negative. If one could get a sine-wave machine, and potentiometers of sufficient accuracy, it is a method which promises a good deal in the hands of a really careful investigator. The author has not drawn attention to one very interesting experiment which we made some time ago at Croydon to show that the current, and even sometimes, owing to the alteration in wave-form, the watts flowing into a cable on open circuit may be actually greater than when some load is put on at the end. We took a long cable of about 7,000 yards, put on an alternator, and measured the capacity current flowing into the cable. We then added a couple of transformers, open-circuited, whose core losses amounted to two kilowatts, the result being that the current entering the cable was measurably smaller than before. That has been repeated a good many times, but I do not think he draws attention to it anywhere here. It merely shows that if properly arranged the capacity of a cable on a large net work may be of advantage rather than otherwise. As a matter of fact it is not actually so deleterious to the supply as possibly is sometimes imagined. I do not think there are any other points that I remember at the time in that connection, but I should like to refer to a remark made in connection with telephones. We had much trouble from Sydenham and Croydon and on to Purley with the telephone cables; we

were a great nuisance to the National Company, and a great deal more nuisance to ourselves. Eventually the manager of the National Telephone Company in that neighbourhood and myself investigated the matter at some length and came to the conclusion that you can take a concentric cable, put it in a lead sheath, in an iron trough, and lay another cable by the side of it also in a lead sheath, and still get any amount of stray field, or what appears to be stray field: you can get enough humming to make it practically impossible to hear on the telephone. Some people say it is leakage, others static effect. We investigated very carefully to find if it was leakage, but we satisfied ourselves entirely that it was not electrical leakage at all. When the current increased in the evening the sound was very greatly increased too; in the day time, when there was very little current flowing in the cable, there was very little noise in the telephone. We came finally to the conclusion that the only really satisfactory way of running telephone cables near high-tension cables was not to trust to any sheathing whatever, but to increase the distance. I shall be glad to hear the experience of other engineers on that point, because it is one which caused us a great deal of trouble. I will not detain the Institution by drawing attention to the number of other uses which the oscillograph is going to have in the future; but there is one in particular which appealed to me, namely, that in specifying high-tension machinery it is now becoming customary to specify the wave form of generator, rotary, or motor generator as the case may be. One has not only to specify voltage, and that sort of thing, but one has to say what sort of wave the machine is to give. Hitherto it has been easy to specify, but it has been difficult to see that you were getting what you wanted. Here you get an opportunity of seeing that the contractor is complying with a specification, an opportunity which hitherto has been impossible. I think every alternate-current station engineer should get his directors to agree that the sum expended on this little apparatus is very well spent indeed. Mr. Minshall

Mr. W. DUDDELL: Messrs. Constable and Fawssett have used three different methods to determine the losses in their cables, viz.:— Mr. Duddell.

(1) The wattmeter method.
(2) The wave-form method.
(3) The extra power required to drive an alternator method.

Of these methods I have no doubt that the wattmeter method is one of the best, if not the best. If a suitable wattmeter and suitable series resistances for the pressure coil are used, accurate results can be obtained, in spite of the wave-forms being as irregular as those shown in Mr. Constable's paper. I hope that Diagram 4, which shows the wattmeter connection, is wrong. In it the pressure coil of the wattmeter is shown connected direct to a resistance marked R_4, with no non-inductive resistance in series with it. If that was really the case, very large errors were introduced. Judging from the oscillograph connections, this appears to have been the case, for the terminals of the resistance R_4 are shown connected straight to the oscillograph, which only requires 1 volt to operate it.

From the text it seems as if they used some resistance in series

Mr. Duddell. with the pressure coil of the wattmeters which they have omitted to show. In any case it would be of great interest to know the values of the resistance, self-induction, and capacity of the pressure coil circuits for each of the wattmeters they used. I hope the authors will be able to give these figures, as they will enable a more accurate estimate of the obtainable accuracy to be formed.

Coming next to the methods of calibrating the wattmeters on power factors less than unity, they state that they calibrated them with a lagging current by using a choking coil. If the choking coil is properly constructed, there is not much difficulty in calculating the true power losses in it. They also state that they obtained a leading current having a power-factor of 0·14. I should like to ask them how they calculated the value of the power-factor in that case. Diagram No. 3 throws no light on the matter whatever, and, as far as I can gather, it is impossible to calculate the power-factor unless they either assume a pure sine wave, or analyse the actual wave used, and calculate each term of the series representing the wave-form separately. There is no indication that this was done. If the actual wave used is that given in Fig. D., which is far from being a sine wave, and if they assumed a sine wave in their calculations, then the calculation of the 0·14 power-factor and the calibration of the wattmeters with leading currents is inaccurate. I hope the authors will explain this matter fully in their reply, as it affects the accuracy of all their wattmeter measurements of the cable losses.

[*Communicated May 6th.* The ingenious method described by Mr. Constable in his reply neglects the self-induction of the fixed coil of his wattmeter and assumes the current A_2 through it in phase with the applied volts V′. Was this self-induction negligible compared with the resistance?]

Ever since Mr. Mordey's paper, Mr. Mather and myself have been working on the design of a satisfactory wattmeter and series resistance, especially for use on very low power-factors, and we have now designed and had in use for some months an astatic wattmeter which is quite free from metal parts in the frame, which has the minimum amount of metal necessary in the coils, and which gives a good deflection, even with very low power-factors. In fact, the wattmeter is so sensitive that with a power-factor of 0·1 you get a complete revolution of the torsion head, so that a power-factor of 0·01 is perfectly easy to read with a high degree of accuracy. We have also designed and constructed special forms of resistances for use in series with the pressure coil, for, as is well known, the errors in these resistances are very often very much bigger than that due to the self-induction of the pressure coil of the wattmeter itself. We have made numerous experiments to test the accuracy of this wattmeter, and we hope to have the opportunity later on of describing it and the resistances. With regard to method No. 2, the wave-form method, it is not very suitable for very irregular wave-forms, unless the wave-forms are actually photographed. It does not suffice to photograph a mean wave-form, as Mr. Field has done. You must get an individual pressure curve and the corresponding current curve belonging to it, and you must work the result out from the

contemporaneous values of the P.D. and current obtained from those two curves. You must not take the P.D. curve of one period and integrate with the current curve of the next, nor take a mean of, say, ten P.D. waves, and work out the power-factor with the mean of ten current waves; you must take each individual pair of curves together, because they may vary considerably. I have on the table the apparatus I use for obtaining photographic records, which records the individual waves and not the mean waves, like the apparatus used by Mr. Field. There are really two sets of apparatus here. One is suitable for working on voltages up to 15,000 with no earth connection, the record being made either on a falling plate or on a long length of film up to about 160 feet where many consecutive wave-forms are required. The other apparatus is for short lengths of film only. Mr. Duddell.

With regard to method No. 3, the extra power required to drive the alternator, Mr. Minshall was, I think, a little inclined to advocate this method. I regret that he has done so, for I totally disagree with him. I have never been able to find any basis for hoping for accuracy from this method. The efficiency of the alternator is totally changed by the action of the capacity current. With ordinary alternators, as I hope to show you presently on the screen, the capacity may produce serious resonances of the higher harmonics, and the effect of adding the capacity current will tend to excite the alternator, and will alter the efficiency by altering the distribution of losses. I see no means of getting over this objection. In fact, sometimes an alternator seems to take less power to drive it if the cables are connected, but most alternators seem to take very much greater power, the iron losses being increased by the high frequency of the capacity current.

Turning to Table No. 4 of Messrs. Constable and Fawssett's paper, they give the results of the tests of five different cables; by taking means of their figures their results may be resumed as follows:—

Cable No.	4	power-factor	2·2 per cent.
"	7	"	11·1 "
"	9	"	2·8 "
"	10	"	7·3 and 2·4 per cent.

This latter value, 2·4 per cent., was obtained with the choker in parallel, and is probably the more accurate, as the wattmeter was then working at a higher power-factor. For the last cable, No. 11, they give two totally different sets of results. The mean of the first set, obtained from curves E, F, G, is 1·4 per cent., and the mean of the second set, obtained from curves I, J, K, is no less than 8 per cent. I should like to ask them what is the difference between the tests E, F, G and I, J, K. In one case they say they obtained 1·4 per cent., and in the other 8 per cent. If you refer to the diagrams of the wave form, you will note that the first three, E, F, G, have a resonance of the fifth harmonic, and in the last three they got resonance in the third harmonic. How is it with the same cable they have these two different resonances? Did they use a different alternator in the two cases, or different frequency, or was there by any chance a transformer connected across the cable in the case of I, J, K? In no case do they give any indication as to the

Mr. Duddell nature of the machine and frequency used in each test. There is no doubt whatever that the self-induction connected between the terminals of the cable tests I, J, K was very much greater than in E, F, G, if the frequency was the same; yet they have accepted the high loss as more probably correct. Taking the figures for the five cables, which are not on the face of them doubtful, the losses, as Mr. Minshall said, are generally under 3 per cent., except in the one case of the No. 7 cable. That cable appears to be a bad cable as far as light-load loss is concerned.

I have tested by means of the wattmeter already mentioned various cables belonging to electric light companies in and around London, and in general the power-factor has varied from 1·5 per cent. to 3 per cent., the power-factor differing from one cable to the next, even when they were very similar in make and construction. I have also tried the effect of varying the voltage used on some cables over a fairly wide range, and find, as Messrs. Constable and Fawssett point out, that there seems to be a tendency for the power-factor to increase with increase of the applied potential difference. The effect of a change of the applied wave-form due to resonance of one of the harmonics has been to make the power-factor larger when the resonance occurred than when there was no resonance, evidently due to the increased value of the maximum instantaneous E.M.F. In all the tests I have so far made—and they have been made under ordinary working conditions, with the cables connected up to the switchboards exactly as used, and no allowance being made for any C^2R losses due to the capacity current—I have never come across a cable giving a power-factor above 3·5 per cent., except the No. 7 cable at Croydon, which I once tested, and I then had doubts as to the accuracy of my own test, as I stated at the time, as during the test there appeared to be such a violent resonance that I could distinctly hear the resistances in series with the volt coil of the Swinburne wattmeter I was using giving a brush discharge, though the R.M.S. voltage was only 2,000 volts. I still feel that this No. 7 cable should be further tested to find out the true cause of the great loss in it, whether it be real or apparent. Messrs. Constable and Fawssett suggest that it may be caused by a magnetic field, though this presents serious difficulties. I asked Mr. Fawssett to make some further experiments on this point, the results of which he will no doubt tell us. The noise in the telephone referred to may well be due to leakage from the outer to earth, and would increase with the load.

Messrs. Constable and Fawssett's paper strengthens the conclusion that it is quite possible to obtain commercially cables with a power-factor less than 3 per cent., and that therefore the danger pointed out in Mr. Mordey's paper of the large power schemes being crippled by the light-load losses in the cables themselves is not at all serious, and I would suggest that we may take warning from Croydon and avoid cables having such absurdly high losses as their No. 7. V.B. cable appears to have. Taking Messrs. Constable and Fawssett's tests of the No. 7 cable as correct at a 1½d. per unit, £50 per annum of the ratepayers' money is being wasted in warming the cable instead of a quarter that amount, and probably 1½d. per unit is an under-estimate

Mr. Duddell.

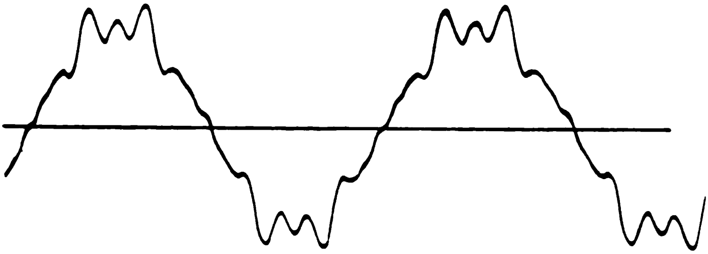


FIG. A.—Alternator on Open Circuit.

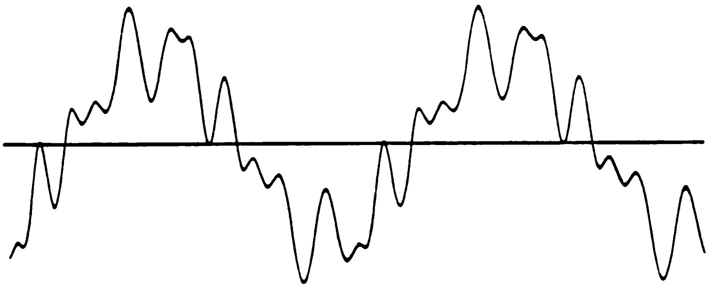


FIG. B.—Alternator and Cables, *Normal* Speed.

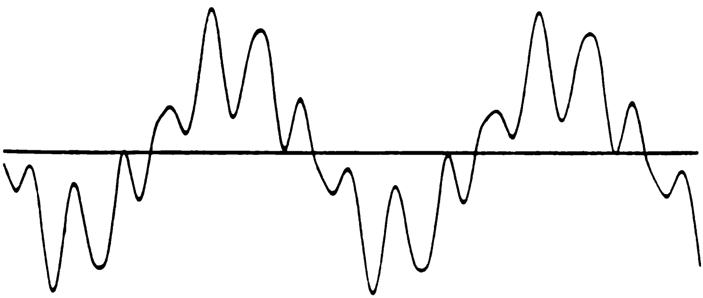


FIG. C.—Alternator and Cables, 8 per cent. *Over* Speed.

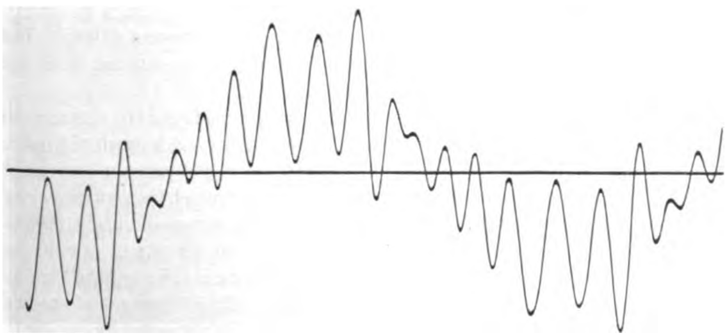


FIG. D.—Alternators and Cables, 26 per cent. *Under* Speed,
Scale: 1 mm. = 458 volts.

Mr. Duddell. of the cost of producing the power. With regard to No. 12 cable, which I believe includes most of these other cables, if you take the total losses, 901, you will find it is very little bigger than the 601 taken in No. 7, so that how it includes the high losses in No. 11 I do not understand.

Turning to Mr. Field's valuable paper on the resonance question. I do not think that he has laid sufficient stress on the dangers to the insulation due to these resonances of the higher harmonics.

Out of four large plants I have recently tested, three suffered seriously from resonances, and Mr. Field and Messrs. Constable and Fawssett show us that both Glasgow and Croydon do. These resonances not only strain unnecessarily the insulation of the cables; they also reduce the efficiency of the machines, make the regulation bad and the working of motors difficult.

Before proceeding I will define the term form factor as the ratio $\frac{\text{maximum instantaneous value}}{\text{R.M.S. value}}$ for any wave-form, a most useful factor which gives a measure of the strain on the insulation due to the wave-form.

I have to thank the Kensington and Knightsbridge Company for allowing me to show some resonances obtained on their circuits which will, I hope, exemplify the danger to insulation due to resonances. In each case the R.M.S. voltage is the same, viz., 5,000. Fig. A is the open circuit wave-form of the one of their alternators; the maximum volts are 1·45 times the R.M.S. volts, or in other words the form factor is 1·45, about the same as for a sine wave. Fig. B is the P.D. wave form of the same alternator with some cables connected which were on open circuit, the alternator running at normal speed; the form factor is 1·67. If, however, the speed of the alternator increases to only 8 per cent. above the normal, a resonance of the seventh harmonic occurs (Fig. C.) and the form factor increases to 1·74. On the other hand, if the machine is allowed to slow down to 26 per cent. under normal speed, a resonance of the fifteenth harmonic takes place (Fig. D), and the form factor rises to 1·94. This shows that, with a constant excitation, lowering the speed of the alternator may *increase* the strain on the insulation. A cable should never be energised by raising the speed of the alternator after exciting the latter, for fear of passing through dangerous resonances; the alternator should be run up to correct speed first, and then the excitation should be gradually raised.

In some other stations I have known the form factor to increase to as high as 2·2; thus, supposing 10,000 R.M.S. volts was applied to the cable, the maximum instantaneous voltage would be no less than 22,000 volts, or, due to the resonance, the cable would be strained with as high a maximum voltage as is given by a sine wave having a R.M.S. value of 15,500 volts, so that a cable designed to work at 10,000 volts on a sine wave might frequently be strained 55 per cent. in excess, due to a resonance of one of the upper harmonics. I think that cable makers have in some cases been unjustly blamed for failures due to resonance. These resonances are a frequent cause of the failure of E.S. voltmeters. It is to be noted that these high peaks on the P.D. wave mentioned do

Mr. Duddell.

not show on the station voltmeter which reads the R.M.S. value, so the engineer in charge has no idea how serious the strain on his apparatus is. It will be said that the ordinary rules of testing to twice the working pressure allows for the above strains. But this is not the case, as the whole of that margin and more is required to allow for the strains due to oscillations without its being reduced in any way due to resonances.

I have calculated the form factors for some of the wave forms in Messrs. Constable and Fawssett's paper :—

Curve	A.	1·89	Curve	E.	1·97	Curve	I.	1·75
„	B.	1·88	„	F.	1·96	„	J.	1·72
„	C.	1·80	„	G.	1·93	„	K.	1·69
„	D.	1·53				„	L.	1·85

The difference between the form factors of curves E, F, G and of curves I, J, K, which are for the same cable, No. 11, show, as I have already mentioned, that the conditions under which these tests were made were evidently very different.

I think the above values, which are in no way exceptional, show

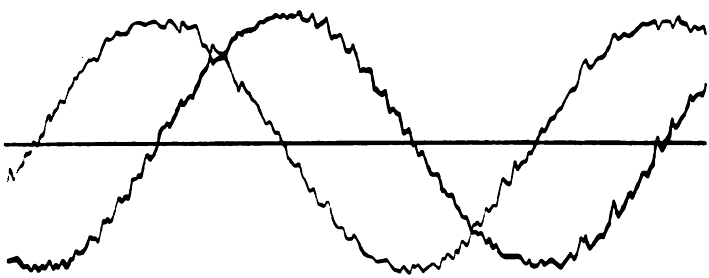


FIG. E.—Converter; Effect of Sparking at Brushes on Direct-Current Side.

how very serious the dangers due to resonances of the higher harmonics are in practice.

Mr. Field has referred to ripples on the D.C. side of a rotary converter. I should like to draw attention to the irregularities which sparking at the brushes of a converter may produce in the P.D. wave-forms on the alternate-current side.

Fig. E shows the two P.D. waves of a small two-phase converter which was allowed to spark at the commutator.

The irregularities in both the P.D. waves due to this sparking are very marked. It seems to me that these high frequency ripples might easily be resonated and lead to very serious difficulties and dangers in working, so that a converter which was working perfectly satisfactorily might, by being allowed to spark at the brushes, cause a serious resonance with the attendant dangers to itself and the rest of the plant.

Prof. Hay.

Prof. A. HAY: In connection with Messrs. Constable and Fawssett's paper, I should like to make a few remarks with regard to the alleged

Prof. Hay. magnetic field which exists around the concentric cable. It is very difficult to believe that such a field can exist, and the only way in which it can possibly be brought about is by a slight excentricity in the inner conductor of the cable; a large amount of excentricity is of course out of the question. It seems to me that the experiments with telephones prove nothing at all, because there is a much simpler explanation, namely, a purely electrostatic disturbance. If you consider the outer conductor of the cable and suppose that it is conveying an alternating current, you will have a periodic rise and fall of potential at each end of the cable. You have your pilot wire in the same trough near the outer conductor, and you are bound to get a considerable amount of electrostatic action between the pilot wire and the outer conductor of the concentric cable. Such disturbances are well known to telephone engineers, and I think that there is no doubt the effects observed are due entirely to purely electrostatic causes and not to electro-magnetic disturbances, as has been suggested by the authors. In connection with the remarks made by Mr. Duddell, I am sorry to note that he is introducing a new term and using an old name for it. He speaks of the form factor of the wave-form. As a matter of history, I believe I am right in saying that Dr. Fleming was the first to introduce certain terms which had definite reference to the wave-forms of alternating currents and P.D.s. The two terms introduced by him were the *form factor*, which he defined as the ratio of the R.M.S. to the mean value of the wave, and the *amplitude factor*, which denoted the ratio of the R.M.S. to the maximum value. Dr. Fleming's amplitude factor is thus the reciprocal of Mr. Duddell's form factor, and Dr. Fleming's form factor is something totally different. As the term form factor has been used by both English and continental writers in the meaning given to it by Dr. Fleming, I hope Mr. Duddell will try and invent some other suitable term for the ratio of the maximum to the R.M.S. value.

Referring next to Mr. Field's paper, I wish to point out that from equation (9) and the further condition $K = \frac{4}{r^2}$ it clearly does *not* follow that the arrangement of branched circuit indicated will be equivalent to a simple non-inductive resistance of r ohms for *all* frequencies, since the equation (9) involves the frequency.

[*Note added later.* On investigating the matter fully, I find that balance for all frequencies may be obtained by making $K = \frac{4}{r^2}$, and that this is the *sole* condition required; Mr. Field's equation (9) is not a necessary condition. Thus Mr. Field's final result is correct, although his manner of arriving at it is entirely erroneous.]

I must further tax Mr. Field with using terms which are out of date. He speaks of ohmic resistance. I should like to ask Mr. Field whether there is such a thing as a resistance which is not ohmic. Then he speaks of the secohm. I should like to know what the secohm is. It is to be regretted that Mr. Field does not see fit to use the modern unit of self-inductance—the *henry*. Again, Mr. Field uses the term "self-induction" in two totally different senses. I should like to suggest the use of the term "leakage self-inductance," and then nobody can possibly

make a mistake; the matter is perfectly clear. If you define self-induction in one way and then proceed to use it in a totally different sense, confusion is bound to result. Prof. Hay.

In Part 2 of the paper Mr. Field states that he is perfectly aware that the peculiar effects obtained during the charging of a condenser are treated mathematically in the various text-books on the subject, implying that the subject had not been dealt with experimentally before. If Mr. Field is interested in the subject, I can give him references to several papers in which curves similar to those he gives are plotted to scale, showing not only the oscillations of the charging current of the condenser, but also the abnormal rises of potential which are produced.

[*Note added later.* The references are:—*Phil. Mag.* for 1892 (vol. xxxiv., p. 389); *Proc. Roy. Soc.* for 1893 (vol. 54, p. 7); *The Electrician* for 1895 (vol. xxxv., p. 840.]

In connection with the higher harmonics of alternating E.M.F. waves, it may be interesting to refer to an arrangement—recently patented by Arnold, Bragstad, and la Cour—in which the property possessed by the third harmonic in a three-phase system is utilised. It is not difficult to show that there can be no third harmonic in the P.D. wave between any two wires of a three-phase system supplied by a star-connected three-phaser; for, since a phase-displacement of $\frac{1}{3}$ period for the main wave corresponds to a phase-displacement of a whole period for the third harmonic, the E.M.F.s corresponding to this harmonic will at every instant be equal and all act either towards or else away from the neutral point. But if the neutral points of generator and motor or transformer (star-connected) be connected through a lamp or motor load, a path will be provided for the high-frequency current corresponding to the third harmonic. Such an arrangement, originally proposed by Bedell, would, however, be practically useless on account of the choking effect of the motor or transformer circuits. Arnold and his co-workers overcome the difficulty by distributing the winding corresponding to each phase over two cores, the connections being such that while for the low-frequency three-phase currents the action remains unaltered, for the high-frequency current the motor or transformer coils are non-inductive. In order to obtain complete control over the high-frequency single-phase E.M.F., the inventors use a stationary armature, in whose core are embedded the conductors of the three-phase winding, but the fly-wheel magnet carries a double set of pole-pieces, one corresponding to the low-frequency three-phase E.M.F., and the other—thrice as numerous—giving rise to the single-phase E.M.F. of thrice the frequency. The advantages of low frequency for power work and of high frequency for lighting are combined in this *polycyclic* system, as it is termed by its inventors. A considerable saving of copper is claimed for it, in addition to its other advantages.

Mr. M. B. FIELD: In common with the previous speakers I attach great importance to the subject of dielectric hysteresis. I think that in all probability it may be intimately connected with the breakdown voltage an insulating material will stand. What I mean is this: if one Mr. Field.

Mr. Field. takes a number of similar slabs of a given dielectric and tests them up to the breakdown point it would probably be found that, other things being equal, that sample will break down first which has the greatest dielectric loss, and I would go further, and say that in any individual sample, provided the electric strain is uniform over the surface, it will probably break down at that spot where the dielectric loss is a maximum. If this be correct it gives us a very good reason for examining minutely this question of dielectric hysteresis quite apart from the cost of the lost power thereby engendered.

Before touching on that point, however, I would like to call attention to the fact that the losses to which Messrs. Fawssett and Constable particularly refer are not wholly confined to the dielectric; a portion, a very small portion it's true, occurs in the copper itself, so that a cable on open circuit which is insulated with a perfect dielectric will always have a power-factor somewhat greater than zero due to the C^2R loss in the copper core which the charging current gives rise to. If C be the charging current, or that flowing into the near end of the cable, and R is the total resistance of the "go and return" conductors, the copper loss will be $\frac{C^2R}{3}$. The apparent power is V C, hence the power-factor is—

$$\frac{C\,R}{3\,V}$$

or writing C as $2\pi n$ K V, n being the frequency and K the total capacity in farads, we may say roughly that—

$$\text{P.F.} = 2\,n\,K\,R.$$

This shows us that the p.f. is proportional to the square of the length of the cable and to the frequency.

Now with ordinary lengths of cables at ordinary frequencies this power factor is extremely small, *e.g.* taking 10 miles of No. 7 cable we should get—

$$\text{P.F.} = 2 \times 60 \times 8{\cdot}36 \times 8{\cdot}8 \times 10^{-6} = {\cdot}0088.$$

This of course is a very small p.f., but if a thirteenth harmonic were present in the wave-form, the p.f. relative to this one harmonic would be over ·11 or practically as great as that noted for Cable 7 in Table IV.

The above rough approximation can of course not be applied for very long cables. In that case we should have to express the p.f. in the following way:

$$\text{If } V = V_0 \sin k\,t$$
$$C = C_0 \sin (k\,t + \eta)$$

at the near end of the cable, then η may be split up into three components, $\eta = \phi + \theta + \phi_1$.

The values of ϕ and θ are given in my paper on page 689, while ϕ_1 is such that—

$$\tan \phi_1 = \frac{\epsilon^{-2al} \sin 2\,a\,l}{1 - \epsilon^{-2al} \cos 2\,a\,l}$$

Now if we assume the resistance of the copper is vanishingly small $\theta = o$ and $\phi + \phi_1 = \frac{\pi}{2}$, which shows us that in this case only can

the power factor be zero. Having now disposed of that component of the loss which occurs in the copper itself, we must look to the dielectric as the seat of the greater proportion of the total loss. Mr. Field.

It is very striking that this dielectric loss can amount to more than one-third of the total C^2R loss in the H.T. cables, for this is what Messrs. Constable and Fawssett tell us.

Towards the end of the first volume of Maxwell the case of a stratified dielectric is mathematically considered, in which different values of conductivity and specific inductive capacity are assumed for the different layers and the phenomena of electric absorption and residual discharge are explained on that hypothesis. We then find the statement that the same reasoning applies and similar results are obtained if instead of assuming definite strata, we consider merely a conglomeration of particles with different constants as above. This is a very useful conception in connection with many manufacturers' insulating materials. Returning to the simpler conception of a stratified dielectric of which some of the strata act more or less as slightly conducting layers and take up little of the static strain, while others act more

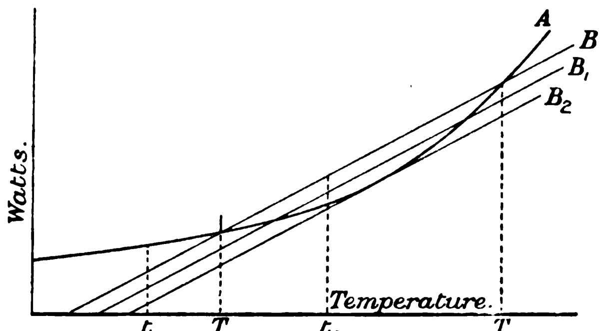


FIG. F.

A = watts generated per square inch of surface due to given voltage at given frequency; B B_1 B_2 = watts dissipated (with different temperature of surroundings).

truly as the dielectric medium in say an air or mica condenser, we see that we could consider a section of the insulation of the cable say between the inner and outer conductors as a succession of capacities and high resistances in series. Testing such a combination with a continuous current, it is clear that the insulation resistance might be very high, since the good layers would take up the static strain. Testing with an alternating current, however, one might find considerable loss and heating owing to the capacity currents flowing through the bad or semi-conducting layers.

In this case the loss would be proportional to the square of the voltage and to the square of the frequency, while the power-factor would be proportional to the frequency.

I notice in Table V. the approximate loss in a paper cable is shown as

Mr. Field. proportional to the square of the voltage, and I would like to ask how this table was derived, whether it rests on experiment or theory.

I said just now that it was probable the "breakdown" strength of an insulating material was closely related to the dielectric loss, and I would like to explain what I mean.

If we place a uniform slab of some dielectric compound between two metal plates so as to form a condenser, apply an alternating voltage, and measure the loss per unit area of surface at different temperatures of the dielectric, we find that after a certain temperature is reached, the loss increases at a very rapid rate. Now the rate at which the heat can get away from the slab naturally depends on a large number of circumstances, but principally upon the difference of temperature between the slab itself and the surroundings. Superimposing the two curves of watts generated (due to a given alternating voltage at given frequency) and watts which can be dissipated (by conduction, radiation, etc.) per square c.m. of surface, we get curves such as A and B in the figure above. At the temperature t_1 the heat generated is greater than that got rid of, so the temperature of the material would tend to rise. At the temperature t_2, on the other hand, the energy which the slab can get rid of per second is greater than that generated, hence there will be a tendency for the material to fall. T will therefore be a temperature at which the material will eventually arrive, since at this temperature the rate of generation of heat is equal to the rate of dissipation. Should however the temperature of the slab by any means rise above T_1, it might be said to be in an unstable state, for the temperature would then continually increase until the insulating properties of the material were destroyed by charring. The effect of increasing the temperature of the surroundings will be to materially raise the final temperature T to which the material will rise, for in this case the curve representing watts dissipated will be B_1 instead of B. Again, if we increase the surrounding temperature still further, we find that there will be no final temperature at all, but that the slab will get hotter and hotter until it chars. If now there is a spot in the slab which is weaker than elsewhere, more heat per unit area will be generated here, and the temperature will rise locally at this point. In fact, it seems possible for the temperature to rise at a weak spot to such a limit that actual scorching occurs there without the rest of the material being damaged. As soon as this occurs the insulation breaks down, an arc follows, and in all probability destroys all traces of the gradual burning which has preceded. In corroboration of this theory, which was verbally explained to me by Mr. Miles Walker after he had conducted a number of experiments in this direction, I would instance the following facts.

1st. The voltage that many materials, such as paper, prepared linen, presspahn, etc., will stand depends in some way inversely as the time of application. For example, a layer of paper will often withstand 15,000 volts for an instant, when it will not stand 5,000 continuously.

2nd. If slabs be tested as above described, and the voltage be applied for gradually increasing periods of time, and if they are examined after each application, it will often be found that scorching has occurred at some point without actually brea ing down, and if the material be

again tested under electric pressure it will finally break down at this point. Mr. Field.

3rd. In testing insulating tubes, etc., it is quite a usual practice to put a number under a high voltage test for a few minutes and then to feel them. The hot ones are cast aside as bad, since it has been found by experience that these would in the long run give out.

4th. Those materials which do not change their composition when subjected to a high temperature are usually found to be the best insulators, *e.g.*, mica, porcelain, glass, ambroin, and even air. Should the above theory be correct, we see that it will lead us to the important conclusion that the breakdown strength depends also on the frequency, and a material which easily burns would be much stronger if tested with continuous voltage than with an alternating. We further see that inflammable materials will have two strengths entirely different, one in withstanding mechanical piercing due to a strain of very short duration where the heating effect cannot come into play, and the other in withstanding prolonged strains. It seems probable that air and certain other insulators only break down through piercing, *i.e.*, in the first-mentioned manner.

To my mind a careful investigation into this whole matter would be of the greatest practical importance to the designers of electrical machinery.

Mr. W. M. Mordey: Mr. Constable and Mr. Fawssett deal with the distribution losses in the very practical form of a detailed examination of the actual losses in the Croydon system. Although we have at this Institution often discussed the subject of lost units, I do not think it has ever been put before us in so telling and complete a way. It is saddening to think that after all the efforts of the last twenty years the losses in a well-considered distribution system should be 22 per cent. of the energy sent out of the generating station. Mr. Mordey.

Such a paper shows clearly the direction in which we must work if we desire to reduce the distribution losses. Some of the losses can only be reduced by an outlay which would be unsound commercially, but some may perhaps be lessened.

The authors treat only of distribution losses. When they have exhausted that subject they may turn their attention to the inside of the station, when they will find there is a loss of coal of about 50 per cent. which, on paper at any rate, is capable of being saved. Then they may study the loss of about 85 per cent. in converting the heat energy of the coal into mechanical energy in the boiler and engine; and when they have studied those few small losses they may continue their investigations and consider the loss of more than 99 per cent. in the incandescent lamp itself between the heat energy given to the lamp and the light energy given out.

You will find, sir, that we shall not exhaust this subject to-night!

Before going on to the matter that interests me a good deal, that of the losses in the dielectric, I would like to refer to the question of switching transformers off, mentioned by the authors at page 723. It is generally believed that for economical working it is necessary to keep transformers as nearly fully loaded as possible—this is

Mr. Mordey.

not by any means the case. There is often no advantage in switching transformers off; there may even be a disadvantage in doing so. The efficiency curve of a good transformer is square-shouldered; it goes up quickly, to practically full efficiency, and then keeps nearly straight up to full load, often indeed falling a little as full load approaches. Now with such conditions two half-loaded transformers are as efficient as one fully loaded; if the curve drops a little, the two will be even more efficient.

For transformers having efficiency curves which reach practically full value at one-third load, three of them, each one-third loaded, will be as efficient as one fully loaded. Under such conditions it is best not to keep transformers fully loaded; it does not save energy, and it is bad for the transformers. If a given amount of energy is to be wasted, it is better to spread it over a number of transformers than to concentrate it in one—better for the transformers, and it lowers the copper loss.

Turning now to the question of losses in the dielectric of the cable, I quite agree with the authors in disliking the term. If the last speaker—who seems to have a liking for correctness in terms—could invent some term which is less cumbrous and more like Anglo-Saxon than "dielectric hysteresis," we should all be very grateful to him.

The paper that I read here some time ago on that subject has been referred to by the authors and by one or two speakers. I was rather badly treated in that discussion; it was apparently felt that in suggesting we had overlooked a serious cause of loss of energy, I had committed a crime of the most heinous character! But time brings its revenges. As the authors say, the subject was not exhausted then, and I am very glad indeed they have contributed to its further elucidation. There is a good deal to be done before we have got to the bottom of that subject. But it is one that we must consider. If there is a possibility of power-factors of anything like the order I mentioned in my paper—now confirmed by the present authors—or, I will go further and say that if there are power-factors of a much lower order—such as Mr. Duddell says he is satisfied do commonly exist—it is a matter of real engineering importance, especially for long distance high-pressure work. We must try and find some simple way of measuring these losses. The authors and Mr. Duddell—an investigator who should be carefully cherished—have used certain methods which are probably the best now available, but we want something more direct. I would suggest calorimetric methods. Direct measurement of the rise of temperature is of course hardly practicable. Under ordinary conditions even a serious loss of energy would not cause any noticeable rise of temperature in a cable.

It ought, however, to be possible to put a cable into a heat-insulated bath of oil or water and to run it and observe the rise of temperature that takes place when it is subject to high electromotive forces. It should then be possible to get the same rise and therefore the same loss by sending a direct current through the conductor of the cable and so measure the direct current energy easily. I do not say there are no difficulties. To what extent the losses are eddy-current losses is a matter to which attention must

be given. But I think there are ways of making calorimetric tests under conditions where, if eddy-current losses exist, they may be kept so small as to be negligible, or, in any case, their amount can be measured. This latter might be done by determining the loss, other than that due to resistance and current, by sending a low-tension alternate current through a cable in the calorimeter; under these conditions there would be no dielectric loss. Mr. Morley.

When I read a paper on Capacity Effects before this Institution, the discussion was associated with a good deal of heat other than what is usually measured by a thermometer. I hope we shall now discuss it calmly and find out seriously whether it is a loss which engineers—makers or users of cables—need consider. It is far more important to be sure that there is a small dielectric loss than that the copper has a high conductivity. If it is necessary to specify the latter carefully, much more important is it to consider a cause of loss which may be hundreds of times greater than that caused by the copper being 0·96 instead of 0·98 of Matthiessen's standard of conductivity.

May I be allowed to give as an example a few figures to show that this matter is of real importance even with small power-factors? It is not denied, I think, that there may be such power-factors as 0·1, but let us take the lower values of 0·025 or 0·03 which Mr. Duddell's experiments lead him to say need not be exceeded in any good cable. I do not, however, agree with him that with such values the matter is of no importance; even a 0·01 power-factor may be of importance. Let us take a case which may easily occur in practice. Assume a 10,000-volt three-phase cable for a transmission system supplying such an area as many power schemes are now proposing to deal with. Assume it has a capacity of 0·3 microfarad per mile, and a power-factor of 0·03—then the loss would be 7,400 units a year for every mile of cable, or about equal to an 8-c.p. lamp, always alight, for every 63 yards of cable. Assume this cable is ten miles long and is supplying a small town having an ordinary 12 per cent. load-factor and a "maximum demand" of 300 kw.—the ordinary "authorised distributor" of the power bills—then the dielectric loss in the cable will be 23·4 per cent. of the energy delivered, or as much (in percentage) as the authors show is lost in the whole system at Croydon in transmission and distribution.

If this is true, the question deserves serious attention.

It would be interesting—in these days of power bills and long-distance high-pressure schemes—to follow this point a little further, but I will only point out that if the copper loss in this cable is 5 per cent., and if the "authorised distributor" loses only 20 per cent. in distribution, then the generating station must send into that cable about 48·5 per cent. more energy than ever reaches the customers. One point, however, must not be lost sight of: the dielectric loss, whatever it may be, does not greatly increase with the size of the cable; thus it will be relatively less serious on a cable for a large load than for a small one. For the latter it may be serious enough to prevent the economical supply of small towns through long underground cables, and may strongly support the demand for bare overhead conductors.

One other point—this loss is not a capacity loss at all, but a kind of

Mr. Mordey.

resistance loss having a unity power-factor of its own; it would take place just the same if the cable had no evident capacity.

The President announced that the scrutineers reported the following candidates to have been duly elected:—

Members.

Ovide F. Domon.
Giovanni Giorgi.
Wyndham Monson Madden.

Associate Members.

Frank Anslow.
Robert Malcolm Campbell.
Johan Denis Carlmark.
John Mathieson Keenan.
Walter Henry Le Grand.
John F. Magoris.
John Frederick Pierce.
Theodore Rich.
Harold Stokes.

Associates.

Arthur Chester.
Edward Alan Christian.
Wm. Frederick Coaker.
Wm. Thomas Dalton.
Theodore J. Valentine Feilden.
Thos. Henry Flamwell.
John Walker Fyfe.
Chas. Ward Hammerton.
Hugh Henry McLeod.
Chas. Edward Harrison Perkins.
Louis Boniface Wilmot.
Clifford George Woodley.

Students.

Herbet Paul Amphlett.
William Bell Begg.
Eric Frank Cliff.
William Prescott Crooke.
Thomas Davies.
Henry T. Debenham.
Eustace Jonathan Down.
Henry Firth.
Charles Butler Grace.
Harry Lillywhite.
Joseph F. Mongiardino.
Leonard John Pumphrey.
Chas. Alexander Rainsford.
Roy Grosvenor Thomas.
Geo. Keenlyside Tweedy.
James L. Wilson.
Martin Julius Wolff.

The Three Hundred and Ninety-second Ordinary General Meeting of the Institution was held at the Institution of Civil Engineers, Great George Street, Westminster, on Thursday evening, April 23, 1903—Mr. ROBERT K. GRAY, President, in the Chair.

The minutes of the Ordinary General Meeting held on March 26th, 1903, were taken as read and signed by the President.

The names of candidates for election into the Institution were taken as read, and ordered to be suspended in the usual form.

The following list of transfers was published as having been approved by the Council —

From the class of Associates to that of Members—

Walter Joseph Higley.

From the class of Foreign Members to that of Members—

Frederico Pescetto.

From the class of Associates to that of Associate Members—

Frederic Robert Bridger.	William Richard Kelsey.
Robert Marshall Carr.	Theodore Arnold Locke.
Robert Tyndall Haws.	Arnold Philip.
Francis C. Hounsfield.	Maurice Solomon.

T. B. Wright.

From the class of Students to that of Associate Members—

Frederic Chas. Kidman.	John Warrack.

From the class of Student to that of Associate—

Arthur John Cridge.	Alfred Eddington.

Messrs. H. Brazil and L. T. Healey were appointed scrutineers of the ballot for the election of new members.

Donations to the *Library* were announced as having been received since the last meeting from Messrs. A. Heyland, H. A. Humphrey, E. and F. N. Spon; to the *Building Fund* from Messrs. B. G. Jones, H. T. Lines, A. Nield; and to the *Benevolent Fund* by Mr. S. E. Britton, to whom the thanks of the meeting were duly accorded.

The Secretary read the following nominations by the Council for the officers and Council for the ensuing Session :—

MEMBERS NOMINATED BY THE COUNCIL FOR OFFICE 1903–1904.

As President.

Nomination.	ROBERT KAYE GRAY.

As Vice-Presidents (4).

Remaining in Office.	JOHN GAVEY. Sir OLIVER LODGE, F.R.S.
New Nominations.	Dr. J. A. FLEMING, F.R.S. J. E. KINGSBURY.

Ordinary Members of Council (15).

Remaining in Office.	SIR JOHN WOLFE BARRY, K.C.B., F.R.S. S. DOBSON. BERNARD DRAKE. H. E. HARRISON. Lt.-Col. H. C. L. HOLDEN, R.A., F.R.S. The Hon. C. A. PARSONS, F.R.S. W. H. PATCHELL. J. H. RIDER. A. A. CAMPBELL SWINTON.
New Nominations.	T. O. CALLENDAR. S. Z. DE FERRANTI. FRANK GILL. F. E. GRIPPER. G. MARCONI. W. M. MORDEY.

As Associate Members of Council (3).

Remaining in Office.	W. DUDDELL. SYDNEY MORSE.
New Nomination.	A. J. WALTER.

As Honorary Auditors.

For Re-Election.	F. C. DANVERS. SIDNEY SHARP.

As Honorary Treasurer.

For Re-Election.	ROBERT HAMMOND.

As Honorary Solicitors.

For Re-Election.	Messrs. WILSON, BRISTOWS & CARPMAEL.

The PRESIDENT: Before the discussion of the papers of Mr. Field and Messrs. Constable and Fawssett is opened, I desire to make a few remarks with regard to the recent visit to the North of Italy of about 120 members of the Institution. The object of these remarks is to place on record, in the Proceedings of the first meeting held since our return, the sense of gratitude felt by the Institution for the great kindness shown by our Italian hosts.

In addition to the many interesting visits which had been arranged, the very cordial reception given to the party was quite remarkable. Senator Colombo, who had been in Rome, made a point of coming to Milan to meet us. Professor Ascoli, the President of the Associazione Elettrotecnica Italiana, also came from Rome to preside at the banquet given in our honour by that body. Mr. Blathy, of Messrs. Ganz and Co., came specially from Buda-Pest to assist in showing us the Valtellina line, in the electrification of which his firm played a preponderant *rôle.* Mr. Cini, of the Adriatic Railway Company, who are interested in the Valtellina line, came from Florence. Our visit to the Tornavento Power Station, with the inspection of the electrified Milan-Varese line, was rendered more instructive and agreeable by the presence of Mr. Kossuth, one of the Directors of the Mediterranean Railway Company, and of Monsieur Lagout, of the Thomson-Houston Company de la Mediterranée, who came from Paris with the object of accompanying us and showing us the work of his firm. Senator Colombo and his friends showed us the large water-power station, at Paderno, of the Italian Edison Company, and also their Distributing Stations in Milan. Senator De-Angeli conducted us to the Vizzola Water-Power Station of the Societa Lombarda per Distribuzione di Energia Elettrica. In addition to these, the Chairman of the Milan section of the Associazione Italiana Elettrotecnica, Mr. Bertini, and the Secretary—Mr. Semenza—had, through the courtesy of the proprietors, enabled us to visit several works in the neighbourhood of Milan and in Milan itself which proved of great interest to the visitors. It is impossible to thank Mr. Semenza too much for the enormous labour he must have gone through to provide for the entertainment of a numerous body. The Council will in due course tender the thanks of the Institution to our late hosts in a more formal manner.

Before terminating I think I should inform the members of the Institution that the visit to the North of Italy is considered by all who took part in it as a very successful one, and that Dr. Silvanus Thompson, who had taken so much trouble in initiating it, Mr. Hammond, the reporter of the Foreign Visits Committee, and our Secretary—Mr. McMillan—who so successfully carried out all the details of the expedition, certainly earned the praise which they received from all sides.

With these remarks I shall now call upon Professor Carus-Wilson to open the adjourned discussion on the papers read by Mr. Field and by Messrs. Constable and Fawssett.

RESUMED DISCUSSION ON PAPERS ON "DISTRIBUTION LAWS IN ELECTRIC SUPPLY SYSTEMS," BY A. D. CONSTABLE, A.M.I.E.E., AND E. FAWSSETT, A.I.E.E., AND "A STUDY OF THE PHENOMENON OF RESONANCE IN ELECTRIC CIRCUITS BY THE AID OF OSCILLOGRAMS," BY M. B. FIELD, M.I.E.E., A.M.I.C.E.

Prof. Carus-Wilson.

Professor C. A. CARUS-WILSON : Mr. Field has brought before us a subject of great importance and interest, and has illustrated his paper by showing us some interesting slides. Mr. Duddell has supplemented what Mr. Field has given us by further illustrations of resonance in transmission circuits, and the jagged, saw-like curves which he showed were calculated to alarm us, especially when accompanied by statements that they involved very high voltage. The question I want to raise to-night is whether the effects that have been shown to us are really serious, in view of the actual strains to which high-tension circuits are subject in every-day working. Mr. Field in his paper rightly alludes to what has been written on this subject in the United States, and draws attention to the communications that from time to time have appeared on this subject in the transactions of the American Institute of Electrical Engineers. I quite agree with him in thinking that those transactions are not as well read on this side as they should be, and I am also surprised that more members of our own Institution are not members of the American Institution. I notice, however, that his paper gives us several results which have already been arrived at by other workers. For instance, the equations he gives us at the bottom of p. 685, for the induced pressure due to sudden and rapid oscillating effects consequent upon breaking a circuit with a load on, are the same as those given by Mr. Steinmetz two years ago, though arrived at by a different process. On p. 691 the equations that Mr. Field gets for the rise of pressure, due to resonance, at the end of the long transmission line, appear to me to be identical in result, with some slight exceptions, to which I will refer later, with those given by Houston and Kennelly in 1895. I refer to these facts simply to point out that Mr. Field has arrived at the same results by working out these problems on independent lines from his own standpoint, in a way quite different from what others have done. On p. 691 Mr. Field gives the fundamental conditions for resonance, and an equation for the rise of voltage at the end of a long transmission line. I do not see why he needs such a confusion of terms at the bottom of p. 688, where he introduces Greek letters as well as Roman letters; I have not quite been able to follow him in that. Surely it is simpler to express the condition of maximum resonance by the expression—

$$l = \frac{\pi}{\sqrt{2}} \frac{1}{\sqrt{(\omega \kappa 1 + \omega^2 \kappa \lambda)}}$$

In the way Mr. Field gives it we have to look back to a complicated series of equations in order to understand it. [*Communicated.* After hearing Mr. Field's explanation of his symbols I admit that his equations are quite as simple as the one I have given above.] I should like to show on the blackboard what this distance l really is. If A is the receiving end and B the sending end, then the pressure is a maximum

Prof. Carus-Wilson.

of V_1 volts at A, and as we get nearer the sending end the pressure drops to a minimum of V_0 volts, and rises again if the line is long enough. The length l between the positions of maximum and minimum pressure is given by the above equation. In practice this distance is very

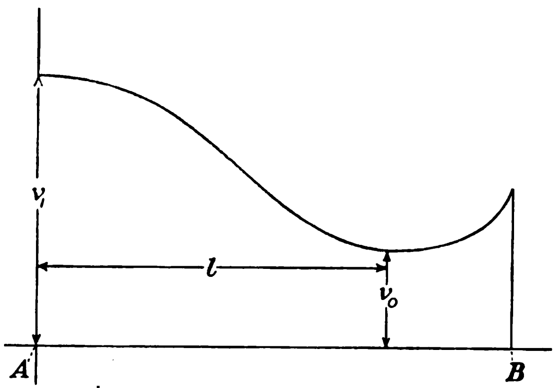


FIG. G.

great. In a case which I had occasion to work out recently for a three-phase transmission line about 100 miles in length, this distance came out to 1,430 miles, that is to say, in order to get the maximum resonance effect the line would have to be 1,430 miles long, whereas the line was only 100 miles long. Consequently the actual rise of voltage due to resonance was a mere nothing. In the next equation Mr. Field gives us an expression for the relation between V_0 and V_1, from which we can find the rise of pressure due to resonance. I cannot help thinking that Mr. Field or his printer has made a slip in that equation; he has in the denominator—

$$- 2 \, \epsilon^{- \pi \tan \theta}$$

I think that should be—

$$+ 2 \, \epsilon^{- \pi \tan \theta}$$

for then that rather complicated equation becomes simply—

$$\frac{V_0}{V_1} = \cosh l \, a$$

That is the usual form of the expression for this ratio, where l is the length in miles and a is the quantity depending on κ, λ, and n.

In the case of the long transmission line to which I referred, taking L at 100 miles, the total rise in voltage did not amount to more than 2 per cent., that is to say, not only is the line required to get the maximum resonance effect of great length, far beyond anything that we get in practice, but the actual rise is quite insignificant. I think it is now generally recognised that resonance effects in long distance transmissions are really of no importance. When we get the frequencies of the higher harmonics that Mr. Field's paper deals with, we get reson-

Prof. Carus-Wilson.

ance effects, but they are so small, on account of the very small amplitude of the waves that are magnified, that the increase in pressure above the normal voltage is a very small percentage when you compare peak with peak or mean with mean. I take it, then, that in actual practice these resonant effects are extremely small in long-distance transmissions, even when you take account of the higher harmonics. But not only that, the effects of resonance, to which allusion has been made by Mr. Field and Mr. Duddell, are altogether insignificant when you come to consider the strains that are actually put upon high-tension transmission apparatus by oscillating discharges. I notice that Mr. Field refers to all the effects dealt with in his paper as resonance effects. I have always understood that the term resonance referred to a stationary wave, the kind of thing shown in the diagram, which is a permanent condition of affairs. That was the meaning of the term adopted by the people who introduced the expression; but in this paper, and in other places also, resonance has come to be applied to a great many other effects accompanying high tension; for instance, oscillatory effects. I quite think that those are the phenomena we have to fear in a transmission circuit, but they are not resonance effects at all, since they are not due to stationary waves—they are due entirely to momentary changes in the conditions of loading the line. These are the really important effects to be considered, since they subject transmission lines to enormous tensions, far greater than any due to resonance. It would be a good thing if we could get some more tests made on these oscillatory effects. The equation for V on page 685 of Mr. Field's paper gives the pressure caused by suddenly breaking a circuit with a load on. The term $\sqrt{\left(V_1^2 + C_1^2 \frac{L}{K}\right)}$ indicates the degree of strain that is put upon the insulating material, from which it appears that the strain upon the insulating apparatus depends upon the load, and is proportional to the current that is being broken, and that if the circuit could be broken when $C = O$ there would be no rise of pressure. This is entirely borne out by tests made on some long-distance transmission lines in the United States, when it was found that the high voltage induced by breaking the circuit was entirely a question of the load that happened to be on the circuit at the instant of the break. When the load was broken under oil, the effect of the break, as shown by means of an oscillograph, was like this:—

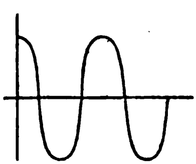


FIG. H.

There is an oscillating discharge extending for a few waves, and then the oil breaks the circuit at the zero point. If it were not for the fact that an oil switch breaks the circuit at zero point, I think it would not be too much to say that high-tension long-distance transmissions carrying very large currents would be impossible. But it is found in practice that the effect of oil is to allow the arc to spring just for a short time, extending over about half a dozen waves, and then to break the circuit at the zero point, that is to say, in a remarkable way the oil switch does exactly what we should want it to do, and breaks the circuit at the moment when the current is nothing, thereby enabling the circuit to be

broken without any rise of pressure. In the tests I referred to, currents of 30 amperes at 40,000 volts were broken by an oil switch without any rise in the voltage being shown on the oscillograph. The danger of breaking a high-tension circuit may thus be less than that of making the circuit, for I do not know of any switch by which the high voltage that you get when making a transmission circuit can be prevented, unless, of course, rheostats are used. It would appear, then, that transmission circuits may be subject in ordinary working to very high pressures due to oscillatory discharges altogether out of proportion to the effects due to resonance, twice, or even three times, that of the normal voltage. I therefore endorse what Mr. Field says at the end of his paper that the oscillatory effects are those that need most to be studied by means of the apparatus we have at hand, notably the oscillograph. Prof. Carus-Wilson.

(*Communicated*): In criticising Mr. Field's equation on page 691, I was under the impression that he was using the terms involving the resistance, self-induction, and capacity as vector quantities, in which case the expression for the ratio of the squares of the pressures at the two ends of a transmission line on open circuit is of the form

$$\tfrac{1}{2}(\cosh 2\,R\,l + 1),$$

R being a constant involving the capacity, etc., and l the length of the line. I see now, however, that he is not using vectors but numerical quantities, in which case the expression is of the form

$$\tfrac{1}{2}(\cosh 2\,P\,l + \cos 2\,Q\,l).$$

$Q\,l$ is the angle of advance in phase of the pressure as the sending end is approached; for maximum resonance this angle is $\frac{\pi}{2}$, so that this expression then becomes

$$\tfrac{1}{2}(\cosh 2\,P\,l - 1),$$

and this is the equation given by Mr. Field, putting cosh for the more complicated exponential terms used in his paper, the sign being rightly negative.

Mr. G. L. ADDENBROOKE: My remarks will bear upon rather a different part of the subject to that alluded to by the last speakers. The paper covers so much ground that it is impossible to deal with all the points in it. As I have had considerable experience in testing cables for what is called dielectric hysteresis, perhaps some account of what I have done might be interesting. My own work began in the following way. Dr. Muirhead some two years ago lent me some of his special condensers for the purpose of investigating the losses which took place in them. I had been too busy to do anything with them up to the date of Mr. Mordey's Institution paper two years ago, but startled by his results I forthwith began some tentative experiments which I mentioned in the debate. Shortly after, I received a communication from the Henley Telegraph Cable Co., who were concerned from a commercial standpoint, and who were rather upset by the possibility of this Mr. Addenbrooke.

Mr. Addenbrooke.

large dielectric hysteresis loss. The result was that they asked me to make some investigations at their works on the subject. The first question which arose was, how these experiments should be made. That really, I think, is the matter which is before us at the present moment, because it is not much good having experiments made until we are pretty certain that the means used for making the experiments are likely to give fairly correct results. I therefore went into this matter. My idea was to employ the electrostatic system of measurement, which I described generally at the International Congress at Paris two and a half years ago. When I came to look into it, it seemed that it would be suitable, and also that it was adapted to meet the following very important point. Going into the calculations with regard to air core transformers for insertion in the circuit, I found it usually meant that you must have three or four microfarads capacity in the cable, in order to keep your air core transformer within reasonable limits, which of course means a long length of cable, which it is very troublesome to deal with and is not very commercial. By using the electrostatic system, even as the system stood intended for ordinary work, I found one could go down to half microfarad with, it appeared to me, a fair chance of being pretty accurate. There is no doubt that by special arrangements it is possible to measure electrostatically the loss in very small capacities indeed—in fact, since the date of my experiments, in a paper in the *Journal of the American Institute of Electrical Engineers*, Mr. Miles Walker described how, by means of a special electrometer used in order that the high pressure might be directly applied to it, he has been able to make dielectric hysteresis measurements on slabs a foot or two square. Therefore it is clear that, apart from its suitability otherwise, the electrostatic system has very great advantages for the commercial measurement of dielectric hysteresis, because we can deal with very moderate lengths of cable.

My apparatus being set up at Messrs. Henley's, arrangements were made for carrying out tests from 2,000 up to about 6,000 volts, and I will give you a few specimens of them. About ·9 of a microfarad of unarmoured lead-covered concentric cable was tested between the inner and outer. I may say that the arrangements at Messrs. Henley's did not, unfortunately, permit of a constant periodicity in all tests being obtained, because they had to vary the speed of the alternator to some extent to get the different voltages, so that the experiments are not so comparable directly as they might have been, but when allowance is made for this they all come very close to each other. The results I got are given in Table I. It is to be noted that the power-factor gradually rose as the voltage rose. Another point that turned up in these experiments was that the results are all somewhat lower than those published by Mr. Mather, which were also conducted on paper cables, and which he mentioned in dealing with Mr. Mordey's paper. Of course there may be different sorts of paper, but as most cable makers deal with the same class of paper, I did not think the difference could altogether be accounted for that way. The question therefore arose whether the difference was due to differences of measurement or to the material. Of course, also, there might have been possible differences

Mr. Addenbrooke.

due to the wave forms that were used in the experiments. Unfortunately, as regards this, I had not the means at my command at the time of ascertaining what these forms were, but I doubt if this can account for all the difference. However, while I was still considering this question some measurements had to be made at Wood Lane on a large inductive resistance which I designed for Messrs. Willans and Robinson for enabling alternators to be tested at proper power factors and which was specified to carry a certain current for six hours at 5,000 volts without undue heating. From the ordinary calculations on a resistance of this

TABLE I.

Cable Tests at W. T. Henley's Telegraph Works, Ltd.

Capacity ·9 mf. Unarmoured lead-covered C.C. Test between Outer and Inner.

Volts.	Amperes.		Watts.	Periods.	Power Factor. Per cent.
	Actual.	Calculated.			
2,040	·24	·33	5·1	28·7	1·04
2,000	·388	·536	10·4	48	1·34
3,000	·36	·486	18	29	1·67
3,000	·55	·7	24	41	1·46
4,000	·36	·452	26·7	20	1·86
4.040	·715	·965	47	43	1·63
5,700	·6	·755	60·4	23	1·72

TABLE II.

Cable Tests at Wood Lane.

Capacity. Unarmoured 3 Core. Tests between Cores A, B, C.

Volts.	Amperes.		Watts.	Period.	Power Factor. per cent.
	Actual.	Calculated.			Cores used.
5,000	1·11	·863	50	50	·9
2,500	·637	·432	18·5	50	1·10
2,500	·95	·69	32·5	50	1·37
5,050	1·68	1·38	102	50	1·2

Mr. Addenbrooke.

sort, made for me by Mr. Berry of the British Electric Transformer Company, we came to the conclusion that the power factor, including the losses in the iron, ought to be about 4 per cent., and the instruments correctly indicated about 4 per cent. Therefore I think this is one fairly strong reason for saying that the instruments were capable of measuring power factors of this sort with close accuracy. In the case of Mr. Miller's cable, which is a three-phase cable, it was tested at 5,000 volts and 2,500 volts. When tested between one core and the other the hysteresis loss came out at about 1·2 per cent., and in one case as high as 1·37 per cent. Again, as in Table II., the results are comparable with the other results I obtained. This was a British Insulated Wire Company's cable of the same kind that Mr. Mather was experimenting with. Having arrived at this point, I thought I would check my working by testing with an air core transformer, that is to say, using the electrostatic system and putting an air core transformer in. For that purpose Mr. Savage, of Henley's, was good enough to have one constructed of flexible, of which they are makers. Dr. Fleming, in his book on electric testing, has put forward an air core transformer as an excellent means, which it undoubtedly is, of finding out whether a wattmeter indicates properly on low power factors because you can with it get a power factor as low as 3 per cent. Having this air core transformer, it occurred to me that I would test my own wattmeter with it. This I accordingly did at Messrs. Henley's before applying it to the cable. The result was that when I came to work out the experiment it appeared as if there was some loss in the air core transformer itself. In the debate on Mr. Mordey's paper it was taken as an axiom that there was no loss in the air core transformer. Not being certain about this, I got the air core transformer sent up to my own laboratory in Victoria Street, where I had the Deptford current. It was again tested at about double the periodicity at which it was tested at Messrs. Henley's. The result was that the loss went up somewhere about as the square, which it would do if that loss was due to eddy currents. I may say that in this case the loss was of the following character. The whole weight of the copper in the air core transformer was somewhere about one hundredweight, and the loss I got at 89 periods was about 36 watts, *i.e.*, about one-third of a watt per pound. When you come to consider the very large number of ampere turns there are on such a transformer, and what a very strong field there is, it does not seem impossible that there should be a loss of this sort. In my case, too, the flexible wire, which was of the ordinary character, happened to be very new. In Mr. Mather's case he used an air core transformer of solid No. 14 copper, as far as I understand. I see from calculations that during his tests he must have had 12,000 ampere turns on the coil, which makes a very strong field. It seems quite possible that he may have lost 50 or 60 or even more watts in 80 lbs. of copper, which deducted would make his results nearly the same as mine. I do not wish to cavil at Mr. Mather's figures. I think he did his experiments somewhat hurriedly, and that to have got as near as he did in the time was almost a feat, because it is a very difficult thing to get reliable experiments with this dielectric hysteresis work. Perhaps I may be allowed to put

Mr. Addenbrooke.

my results into ordinary figures, because I think it is very important we should recognise that, at any rate for practical purposes, the dielectric hysteresis loss in itself is not very serious. In the case of Mr. Miller's cable, which was a three-phase feeder, 2½ miles long, working at 5,000 volts, the actual loss was about 100 watts, or 40 watts per mile. I may say that that was tested without any load on, and therefore perhaps we had rather a bad curve, in fact, the main was actually tested afterwards by Mr. Duddell with the oscillograph, and the results were shown on the screen at the last meeting. Unfortunately I cannot say now which of Mr. Miller's cables the test was made on, but it may be of interest to know that one of Mr. Duddell's results is the wave with which my tests were made.

There are one or two general conclusions I should like to mention. On another occasion a fresh set of cables were put up for experiment. Unfortunately I was not there myself, but my assistant, Mr. Robinson, who really works my instruments better than I do myself, conducted them. In this case there was an iron sheath outside the cable, and the whole of the results came out higher than in other cases. As far as I know the cables were exactly the same; this bears out some results that have been given in the paper we are discussing. I was rather afraid to publish these particular results at the time, as my theoretical friend pulled a long face, but as the matter has been brought forward in another form, I mention that in that particular set of experiments we did get 30 or 40 per cent. increase in the loss when the cable was covered with an iron sheath. There is another general point which I think is worth bringing forward with regard to this dielectric hysteresis loss. These losses go up with the voltage to some extent; as a matter of fact the voltage on one occasion was carried out nearly as high as 11,000 volts, or as much as the cable would stand, with a view of seeing what would happen. The watt losses go up more than proportionally, so that if you keep the wattmeter on and watch it, it really forms a sort of guide to what is going on in the cable, and when you get near the breaking point you get a very great increase of the watt losses. I am inclined to think that a measurement of this class may be very useful in testing cables as to what they are likely to stand, in lieu of simply putting on a breakdown voltage, or say two or three times the working voltage. In testing a boiler, no one would think of testing it up to its breaking pressure, as to do this would cause permanent damage; and, in the same way, by putting too high a pressure on a cable its resisting powers may be permanently injured, but tests, at a few gradually increasing voltages, of the watt loss with an alternating current will enable a curve to be constructed from which the behaviour of the cable can be seen and the point beyond which it is undesirable to press the voltage can be predicted.

Mr. Sparks.

Mr. C. P. Sparks: The two papers before us show how much we are indebted to Mr. Duddell for the oscillograph. I regret to have to say this, after so many other speakers have mentioned the matter, but as I have worked with him a good deal, I feel how much we are indebted to him for such an efficient instrument to attack some of the more obscure problems in connection with transmission work. Mr.

Mr. Sparks. Field's paper brings prominently before us the difference between the modern three-phase generators with an irregular wave form, and the old type of single-phase machines. In Mr. Field's paper, the author directs attention to the advisability of localising the characteristics of each system with the oscillograph. I cordially endorse his recommendation. Some three years ago, my attention was directed to the effect of running up an excited generator on mains of high capacity when it was found that as the frequency rose the current passing into the mains rose suddenly to a high value, and then fell with increasing pressure and frequency. This occurred twice before the working frequency and pressure were reached. The oscillograph at once showed what was happening. Some tests which Mr. Duddell carried out for me with the oscillograph, with the moving film, showed that all variations in the number of mains, generators, and, in our case, throw-up transformers should be made at standard frequency. Hence it is usually dangerous to energise a main by running up from a separate generator or motor-generator, unless the working frequency be reached before the alternator is excited. At the Deptford station, Mr. Partridge introduced ten years ago the method of energising the mains through a transformer, the secondary of which was gradually short circuited. Tests showed this method to be safe, so long as the resistance of the secondary did not fall below a critical value. The use of such an apparatus is generally limited to generators of the copper armature type, owing to the absence of harmonics, and this system cannot generally be applied to the present form of three-phase generators. The safest method to switch on a main is through a non-inductive water resistance, which is gradually cut out over a period of a quarter of a minute. Last year Mr. Duddell took records of switching on cables under these conditions, and it was found that as long as a period of something like a quarter of a minute was taken no undue rise of pressure occurred in switching on cables, the longest length being 14½ miles. The actual length tested was something like 8 miles.

The modern oil break switch efficiently disconnects the feeders under normal conditions of load. Mr. Duddell took records which showed that, as pointed out by a previous speaker, the current is apparently always broken at the zero point, and under all normal conditions the circuit was broken without any dangerous rise of pressure. The most dangerous operation is the removing of a short-circuited feeder, as in addition to the heavy current to be broken the frequency of the station may be affected. Up to now the only really safe condition to remove such a feeder is by keeping your frequency up, and reducing the pressure momentarily in order to disconnect the feeder.

Mr. Campbell. Mr. A. CAMPBELL: With regard to Mr. Field's method of testing whether his water resistance was non-inductive or not, I think he might have done so more easily by trying if at every moment the ordinates of the current curve had a constant ratio to those of the voltage curve. If this is not the case, the circuit is not non-inductive.

(*Communicated*): The simpler method would, however, give no indication of the value of the power-factor.

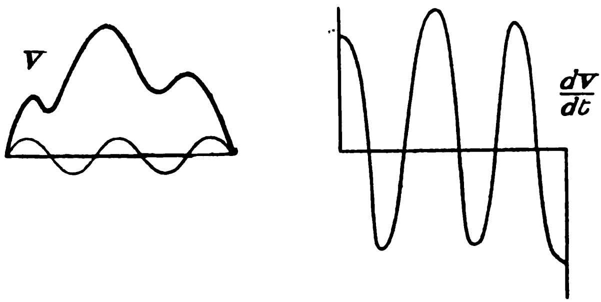
Mr. W. DUDDELL: Mr. Campbell has pointed out that the two curves should be exactly similar. Unfortunately, for watt meter measurements where considerable accuracy is required, an error of one minute of a degree is a serious matter in the lead or lag of the current through the resistance. One minute of a degree is $\frac{1}{60}$th of $\frac{1}{180}$th, or $\frac{1}{10800}$th of a half period. I do not think it is possible to plot a wave form with sufficient accuracy to show a lag or lead of that order. I am afraid some other method has to be used, such as employing a very high frequency in order to determine such small angles. Mr. Duddell.

Dr. W. M. THORNTON (*communicated*): It is to be regretted that Mr. Field was unable to make observations at the generator end of the cables, or on the high-tension side in the sub-station. There can be little doubt, after comparing this and Messrs. Constable and Fawssett's paper, that the harmonics of Curve XV. are chiefly due to the capacity of the cables; but *resonance* is so violent and sudden a phenomenon that one is impelled to ask whether there may not be any other explanation. Dr. Thornton.

As I understand the method of experimenting, the curves were taken from the low-tension side of a 175 k.w. transformer, unloaded. There is then entering the cables the charging current together with a small transformer current. But the secondary voltage of a transformer is proportional to the primary *current*, and therefore any disturbance of this by the distributed capacity of the cables will be inevitably felt on the secondary side, though the conditions may be far from resonance.

According to this view, the greater the capacity of the cables between generator and transformer, the greater would be the amplitude of the harmonics on the voltage wave observed on the low-tension side of the transformer.

The remarkable capacity currents caused by strong harmonics can be seen by drawing the rate of change of the voltage against the generated wave: this representing the current to a suitable scale.



The intensity of the harmonics depends very much on excitation, and one is led to ask whether the conditions of excitation were precisely the same in Curves XV., XVI., XVII., XIX. They are widely separated in time, and it is possible that all the conditions might not have been repeated, especially if the tests were made in the early morning on a very light load.

Dr. Thornton.

With regard to the remark on page 655, that the field currents are not much disturbed by armature reaction, I have found that a variation of 5 per cent. is common in a separately excited three-phase bi-polar converter, and I should think that in a multi-polar machine on full load the effect would be even more marked on account of the relatively smaller time-constant of the windings.

Harmonics in the voltage wave, on reaching the undisturbed magnetic circuit of a converter, *will reproduce the magnetic conditions which started them*. And if the iron is not saturated, the disturbance so caused may be sufficient to increase the amplitude of the ripple in the continuous voltage. This would account for the large ripples recorded, and they should be larger the greater the angle of lag.*

On page 655 Mr. Field attributes the smoothing out of harmonics when two or more generators are in parallel to the increased inductance diminishing resonance. I made observations in the Wallsend power-house of the Newcastle Electric Supply Co. two years ago which led me then to believe that the obliteration of harmonics which was always noticed when several generators were in parallel, was really caused by difference of phase in the respective machines, for on tracing a wave with strong harmonics, displacing it a few degrees from the original and taking the mean, the harmonics in the resultant wave are much less prominent. This small difference of phase may be the result of variable turning moment and will then give rise to synchronising currents which usually reverse in time with the engine; a change in excitation of one of the machines in order to distribute the station load as desired, will produce the same interchange of current which will now, however, not change sign.

The commencement of Part II. deals with the growth and decay of currents in large inductive circuits. I would refer Mr. Field to a paper † read before the Newcastle Section last session, in which an oscillograph was used for the same purpose, and where I gave a more complete analysis of the curves obtained.

Mr. Atchison.

Mr. A. F. T. Atchison (*communicated*): Mr. Field's very interesting paper brings before the notice of electrical engineers the existence in practice of some phenomena which have hitherto been considered as possessing chiefly theoretical interest. The oscillograph is an instrument which opens out great possibilities for the investigation of phenomena taking place in alternating-current circuits, and it is of special value in revealing the many secondary effects which are ignored in the ordinary mathematical treatment of the subject such as is given in the greater proportion of our text-books. This treatment of alternating currents is, and will always remain, one of the most striking applications of mathematical analysis to practical work, but researches such as those of Mr. Field and others, assisted by the oscillograph, serve to show that the common methods of calculating alternating-current problems, though correct in the main, are necessarily somewhat superficial and incomplete. One of the chief omissions in the ordinary theory is the neglect

* The *Electrician*, Jan. 30, 1903, p. 609.
† *Ibid.*, April and May, 1902.

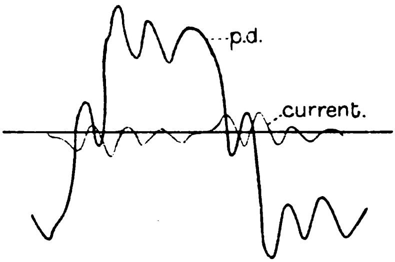


FIG. K.—Capacity 9·0 m.f.

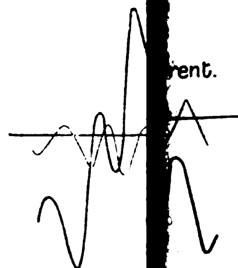


FIG. L.—

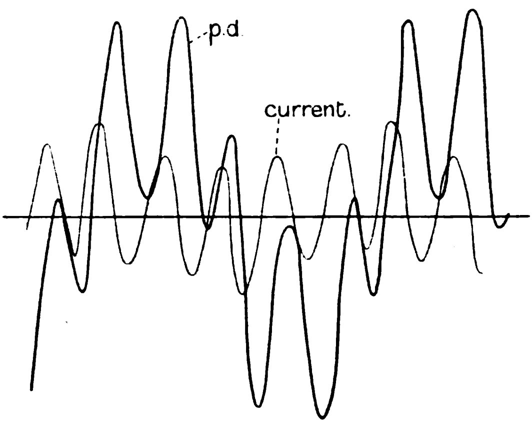
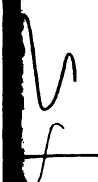


FIG. O.—27·25 m.f.
Exact Resonance with 5th Harmonic.



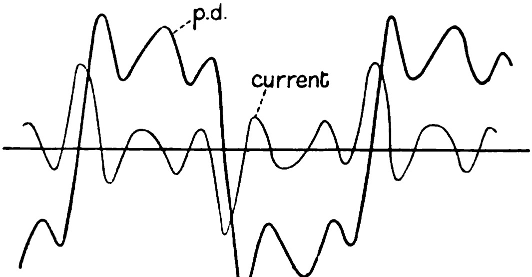
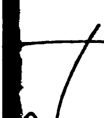


FIG. S.—36·75 m.f.



Circuit.

P.D. AND CURRENT OSCILLOGRAMS FROM A

of the *change* in wave-form which may occur under certain conditions and which Mr. Field has brought before our notice in his admirable paper. Mr. Atchison.

The change of wave-form which may result from resonance with *high* harmonics or "ripples" of the fundamental wave through capacity of certain values existing in the circuit are very interesting, and are shown very clearly by the oscillograph. The effects however may be very much more important, when resonance occurs with *lower* harmonics.

As an example of the great extent to which these harmonics may be brought into prominence, I give a series of oscillograms taken (with a Blondel double oscillograph) from an alternator working on capacity loads of different magnitudes, bringing in marked resonance with the fifth harmonic (or overtone of quintuple frequency).

The E.M.F. wave-form of the alternator on open circuit is shown in Fig. U, containing pronounced triple and quintuple harmonics, and is found to undergo but slight alteration on a non-inductive load. A gradual increase of capacity, however, gives rise to the series of wave-forms given in Figs. K to T; very well-marked resonance with the fifth harmonic taking place with a capacity of 27·25 microfarads in circuit (Fig. O); the current during this stage being practically a simple sine wave of 5 times the fundamental frequency of the alternator, each component being naturally in quadrature with the corresponding peak and hollow in the P.D. wave. A further increase of capacity destroys the resonance, as would be expected, and the wave-forms become more normal. Even at resonance with the fifth harmonic the rise of voltage across the alternator terminals amounted to 43 per cent. (rising from 200 to 286), and had I been able to increase the capacity still further, so as to bring about resonance with the third harmonic, no doubt the effects might have been magnified to an even greater extent. The rise of voltage is of course partly due to the fact that the machine is supplying a leading current and is therefore working with a strengthened field.

It is interesting to calculate the value of the "apparent reactance" of the alternator armature, from the value of the capacity which gives rise to resonance. The frequency of the fundamental wave was 57 ∿ per second, and thus, taking 27·25 m.f. as the capacity corresponding to exact resonance with the fifth harmonic, we have

$$p_5 \mathrm{L} = \frac{1}{p_5 \mathrm{K}}$$

$$= \frac{1}{2\pi \times 5 \times 57 \times 27{\cdot}25 \times 10^{6}} \text{ ohms}$$

$$= 20{\cdot}5 \text{ ohms at the frequency of the 5th harmonic}$$
$$(5 \times 57 = 285 \sim \text{ per sec.}).$$

i.e., a reactance of 4·1 ohms at the fundamental frequency, which is not very different from the value, 4·38 ohms, which was obtained from the "open" and "short-circuit characteristics" of the machine—the "Synchronous Reactance" of the American writers.

Mr. T. MATHER (*communicated*): The best thanks of the Institution are due to the authors for putting such valuable data before its members. Mr. Mather.

Mr. Mather. The communications will, it is hoped, induce central station engineers to pay more attention to the testing department of the works under their control, with a view to locating and reducing the various losses which inevitably occur in the distribution of electric energy. We may also hope that further data as to losses in generation will be forthcoming.

The paper is specially interesting because of the large number of wave-forms met with in actual practice which it contains. These illustrate in a striking manner how the shapes depend on the load on the station and on the feeders connected with the 'bus-bars. Another valuable part of the paper is the section dealing with the measurement of dielectric losses in cables; and Table III., giving the "constants" of the wattmeters employed in the tests, is instructive in showing how much the so-called "constants" of such instruments may vary when used under different conditions.

Every one who has attempted to measure power in circuits of low power-factor with any approach to accuracy will appreciate the difficulties met with by the authors in their efforts to obtain consistent results, for the trouble rapidly increases as the power-factor decreases.

The Swinburne wattmeter behaved better than the Thomson instruments, yet, according to the value in Table III., the "constant" of the former decreased nearly 30 per cent. on changing from a leading current, power-factor 0·129, to a lagging current of power-factor 0·034. This would indicate that the pressure circuit was inductive, and I would ask whether the instrument ever gave negative readings on any of the cables tested?

The change of "constant" here observed is quite moderate in amount when compared with that shown by other instruments on the market, and which claim to be non-inductive. One I tested some two years ago gave results six or seven times as high as they should have been on a condenser circuit, and about one-third of the correct value on a choker. The true "constant," *i.e.*, the number by which the deflexions of the wattmeter have to be multiplied to get "watts," was therefore twenty times as large in the latter case as in the former. The wattmeter itself was fairly good, and the fault lay in the pressure circuit resistance coils supplied with the instrument. These coils, although wound in the way invented by Mr. Swinburne for minimising induction and capacity, are decidedly anti-inductive, *i.e.*, the current through the coils leads on the P.D. between the terminals. In fact the lead was quite measurable by the contact-maker method at a frequency of 100. On replacing the coils by another resistance of better design the readings of the wattmeter became correct within a few per cent.

As Mr. Addenbrooke has referred to the measurements of dielectric hysteresis by the aid of "air core transformers" (ironless chokers) made by Professor Ayrton and myself in 1901, I take this opportunity of answering some of his queries. In the first place I agree with Mr. Addenbrooke that the value of the power-factor for paper cables then published is somewhat higher than the average for high-tension cables of that make. I would also point out that although our measurements of power-factor gave results far less than Mr. Mordey's tests, our low values were some-

what higher than the correct ones. One reason for this is that (as was pointed out at the time, *Journ. I.E.E.*, vol. 30, p. 412) the cables tested were intended for low pressures, but were tested at 2,000 volts. The slope of potential in the dielectric was therefore greater than is usual in high-pressure cables, and this usually means greater power-factor. Another reason why the low value we gave is too high, is that the eddy current loss in the choker was neglected in these tests, and this, as I pointed out in the *Electrician* (March 8, 1901, p. 750), makes the power-factor appear higher than the true value. This effect of eddy currents loss is indicated on p. 413 of the *Journal* (vol. 30), for the tests made without the choker, Fig. D, gave the smallest power-factor, viz., 0·023, whereas those with the choker, Figs. B and C, gave 0·025. Mr. Addenbrooke's estimate of the eddy loss in our choker, 60 watts, is, however, too liberal. Possibly this is due to his taking the ampere-turns on the coil as 12,000 instead of 8,000. A third reason for our low power-factors being in excess of the correct values is found in the fact that, although the coils used in the pressure circuit were the most perfectly non-inductive resistances then made, they were slightly anti-inductive. This caused the current in the pressure circuit to lead on the P.D., and made the wattmeter read high on circuits taking leading currents. It will therefore be seen that the numbers I published in 1901 for the power-factors of paper, indiarubber, and jute cables, although only a small fraction of Mr. Mordey's value, were actually higher than the real ones. Mr. Mather.

Since 1901 I have, with the kind permission of Professor Ayrton, tested other paper cables at 2,000 volts, using in the pressure circuit of our wattmeter the improved resistances mentioned by Mr. Duddell in this discussion; the power-factors obtained varied between 0·015 and 0·019.

During his remarks Mr. Addenbrooke said one of the disadvantages of using "ironless chokers" in cable tests was the large capacity (three or four microfarads), and therefore long lengths of cable, necessary to produce resonance. In this connection I may mention a choker constructed at the Central Technical College two years ago, and referred to in the *Electrician* of March 8, 1901 (p. 750). This coil has an inductance of nearly 6 henries, and will balance about 0·4 microfarad at 100 $\sim$; it contains 1 cwt. of No. 18 wire, and absorbs only 24 watts at 2,000 volts. The question of a choker necessary to balance a small capacity is, however, merely a matter of design, and there is no difficulty whatever in making a choker suitable for testing 110 yards, or even shorter lengths, of cable.

Considerable improvement in sensitiveness and accuracy has been made in dynamometer wattmeters and shunt resistances during the past few years, and it is now possible to measure the loss in short pieces of cable. Twenty-yard lengths have been tested with comparative ease. The currents taken by such lengths of small capacity cables were very small, but were easily and accurately measured by shunting an electrostatic voltmeter with non-inductive resistances.

Tests have also been made (using improved apparatus) on condensers, with the result that the power-factor of some Swinburne

Mr. Mather condensers were found to be below 0·008, and of some condensers made by the late Mr. Cromwell Varley more than thirty years ago below 0·004. For much assistance in these tests I desire to thank Messrs. Few. Finnis, Nesfield, and Selvey, students of the Central Technical College,

It is of great interest and importance to notice that the condensers made by Mr. Swinburne some ten years ago show losses very much less than modern cables. This is highly creditable to our late President, especially as the dielectric in these condensers is very thin compared with that on high-tension cables, and the potential gradient in the dielectric correspondingly great. As condensers can thus be made with dielectric loss about half that of modern cables, it should be possible to reduce the power-factors of cables to half the values now usual. Makers of cables will doubtless give this matter their careful attention, especially where extra-high-tension cables are concerned.

In connection with Mr. Field's paper I might mention a simple way of detecting which harmonics are present in the wave-form of a machine. This is to watch the ammeter in circuit with an unloaded cable (or condenser) as the machine slows down. If any important harmonics exist the reading of the ammeter, instead of falling gradually, will remain steady, or even rise when the speed reaches a value which causes any particular harmonic to resonate. With some machines several rises may be observed before the alternator comes to rest.* The method may be made quite safe by introducing sufficient non-inductive resistance in the circuit to prevent the rises becoming excessive.

Mr. Constable. Mr. A. D. CONSTABLE, in reply, said: I have to thank you, gentlemen, on behalf of Mr. Fawssett and myself, for the considerate treatment which has been accorded to our paper, notwithstanding its shortcomings. Some of the inconclusive figures given in Table 4, with regard to cable losses, would not have been placed before the Institution had it not been for the fact that it was impossible to continue the experiments and further verify the results. The results were given as obtained, and we hoped that they would be discussed, with a view to deciding the causes of the discrepancies. I will try to treat the various points raised as far as possible in the order they occur in the paper. Mr. Minshall referred to the cost of lost units being very heavy because the greater proportion takes place at times of maximum load. It is true that about 60 per cent. of the loss occurs at times of heavy load. That means in this particular case (where the total loss is 22 per cent.) about 13 per cent. additional plant has had to be put in to supply those wasted units, beyond what is necessary for the maximum useful load. The whole annual cost of this 13 per cent. extra plant must be put down to the units wasted during the time it is running only, and although as a rule the actual running cost is rather less during heavy loads than during the day, the total cost may, therefore, be high. In certain cases also, where it is necessary to run an additional generator owing to the day-load losses, these will cost more than the average per unit generated.

* See *Electrical Review*, May 31, 1901, pp. 915–917.

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A question was asked about Table 1. This Table includes the losses from the generator terminals to the feeder terminals. The percentage (0·5) is small, but it represents an expenditure of about £80 per annum, so that if £200 or £300 additional capital outlay would save, say, one-third of the loss, it would be worth while spending it.

Mr. Duddell's objections to diagrams 3 and 4 are unfounded, as he hopes. We had a large non-inductive resistance in series with the pressure coil of the wattmeter in all cases, and also in series with the volt coil with the oscillograph, but it is omitted in the diagrams. The total resistance of the wattmeter shunt circuit was about 7,000 ohms, so that the pressure coil is taking rather less than 1 per cent. of the total current in the resistance R_2, Diagram 3. In connection with Diagram 3, Mr. Duddell asked how we obtained the power-factor with a leading current. I will try to explain this by means of a diagram.

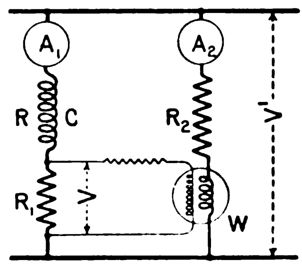

FIG. V.

R_2 is a non-inductive resistance in series with the wattmeter current coil, and the current in it, A_2, is in phase with the applied volts, V'. C is the ironless choker with resistance, R, and in series with it is the non-inductive resistance, R_1.

The wattmeter pressure coil is connected to the terminals of R_1, the voltage across which is V. A_1 is the current in C and R_1.

V is in phase with A_1, and since A_1 lags behind V', the current A_2 is leading with regard to V.

The watts absorbed by the choker $= A_1^2 R$,

" " " " $R_1 \quad = A_1 V$;

the total watts in the choker circuit therefore equal $A_1 (A_1 R + V)$, the corresponding volt-amperes $= A_1 V'$; therefore the power factor of the choker circuit is equal to $\frac{A_1 (A_1 R + V)}{A_1 V'} = \cos \theta$, where θ is, by the usual definition, the equivalent angle of lag of A_1 behind V'.

The watts indicated by the wattmeter will be $A_2 V K \cos \theta$, where K = constant of instrument, so that—

$$K = \frac{\text{Reading}}{A_2 V \cos \theta} = \frac{\text{Reading} \times V'}{A_2 (A_1 R + V) V} \left(\begin{array}{c}\text{R.M.S.}\\ \text{values}\end{array}\right).$$

If now we are not dealing with sine waves, the voltages across C and R_1 respectively may be different functions of the time, so that $A_1 R$ and V cannot strictly be added, but with the wave forms used in the calibration, the error thus introduced will be very small.

[*Note added later.*—I am now obliged to admit, on further consideration, that the possibility of errors being introduced by accepting this calibration may be greater than was at first supposed. In reply to Mr. Mather's query, I may say that the wattmeters used in our experiments did not at any time give a negative reading on the cables tested.]

Mr. Constable.

It is true that the calibration is only quite correct for the particular wave forms used, and in the cable experiments the wave forms were sometimes very different. We do not profess that all the figures in Table 4 are absolutely accurate, but what we attempted to show and tabulate in Table 3 was that the wattmeters gave an approximately correct reading for both lagging and leading currents and for considerably different wave forms. We agree with Mr. Duddell that the wattmeter method is by far the best to obtain the power factor in a cable if a wattmeter can be obtained which will indicate watts only and not concern itself with several other things as well. I am glad to hear that such an instrument has been devised by Mr. Duddell. The motor alternator method might be of use, but it is rather complicated and requires a number of simultaneous readings and adjustments to make it practicable. Mr. Mordey rather advocated the calorimetric method, which certainly cannot be used after the cable is laid, and if the cable is coiled in a tank inaccuracies are introduced, as Mr. Minshall has found. The method might be used if a specially lagged trough were made, of considerable length, as suggested by Mr. Mordey and Mr. Minshall, and the temperature rise in a given time measured; but even in the worst cable, No. 7, the watts lost per yard are only about 0·6, so that there would be some difficulty in measuring the temperature rise accurately in an iron trough, such as should be used.

Mr. Duddell's vigorous criticism of Table 4 was perhaps justified by the appearance of some of the figures. We do not profess that these figures are all even approximately accurate. Where great discrepancies appear, the figures are inserted to show what divergence may occur even in experiments made with care. Cable No. 7 is without doubt abnormal, while the variations in Nos. 4, 7, and 9 are hardly larger than would be expected from the conditions. Cable No. 10 is an exception. Of the two very different values obtained for that cable, the second, namely, 0·024, was obtained with the choker in parallel with the cable, and is therefore probably the more accurate. The low insulation, 2 Ω, is due to switch base leakage, and not to the cable. In the case of experiments 1 to 13 the figures are the means of several sets of readings. The frequency in all cases was 60 $\sim$, within 1 per cent. With regard to cable 11, Mr. Duddell accused us of arbitrarily selecting results and of failing to draw the proper inferences from the experiments. The reason for selecting experiments 18 to 20 in preference to 15 to 17 are given in the paper on p. 716. These experiments were made with different machines. Nos. 18 to 20 were taken with a 120-kw. machine, whilst Nos. 15–17 were taken with a 30-kw. machine of the same type, and there was no other difference to account for the former being the much smoother waves. It is practically impossible to work out oscillograph curves when the waves are very peaked, but the results of the smoother waves should be fairly accurate, though we do not suppose that either result is quite correct. Unfortunately we had no suitable wattmeter available at the time, and there has been no opportunity of checking the results since. As to the effect of the wave-form on hysteresis loss, we prefer to judge by the majority of the experiments, which show there is not such a great

Mr. Constable.

difference as experiments 15 to 20 indicate, although there is some variation. Mr. Duddell also remarked on the low result obtained for the watts absorbed by cable 12. We only obtained 900 watts, whereas the figure should have been about 1,100, summing up the watts absorbed in the various component parts, after correcting for voltage. But again this experiment was made without a wattmeter, and so there is a good deal of possibility of error in working out the results.

Mr. Field questioned Table 5. In that table the figures in the last column were calculated from data obtained by experiment. We took the readings on cable No. 7 and observed the watts absorbed, but as this was an abnormal case, we wished to correct them for a hypothetical paper cable. The results are therefore only approximate, as stated. Our experience goes to confirm Mr. Field's remarks to the effect that a dielectric with a high hysteresis loss has a low disruptive strength. With regard to the magnetic field stated to exist round a cable, since writing the paper we have made some further experiments. A large alternating current, 250 amperes at 60 $\sim$, was passed through the inner and back by the outer of 50 ft. of cable of the type of No. 11, Table 4, in a straight length. At the centre a piece of cast-iron trough 6 ft. long was placed. Three feet of the trough had the cover removed from it. A search coil 18 in. by 5 in., consisting of 200 turns of fine wire connected to a telephone, was fixed (at the same distance from the centre of cable) (A) over the uncovered portion of cable, (B) over the uncovered portion of trough, (C) over the covered portion of trough. In position (A) the noise was very loud, at (B) it was much less, and at (C) there was practically silence. The noise in position (A) was roughly the same as that produced by a current of 2 amperes in a long straight wire at the same distance from the coil (about 2½ in.). That seems to show that there is an external magnetic field which is practically all shielded by the iron trough. A piece of concentric armoured cable behaved in the same way, but the shielding effect of the thin armour was slight. Cable 7 has the outer conductor of a rather open strand, so that the external field may be greater than in the case of No. 11, which has a closely laid outer. (It is difficult to see how this field can exist, however.) It will be of interest to pursue these experiments and investigate the strength of field in the iron trough at ordinary loads. It still appears possible that some of the apparent dielectric hysteresis loss is really iron loss in the case of No. 7 cable.

Mr. Mordey stated he thought it was more economical to allow several transformers to share the load than to keep one or two fully loaded. We admit that. Our point, however, was that it was very wasteful to keep many transformers on at times of no load, and these times make up the greater part of the 24 hours.

Mr. Andrews referred to the danger of switching off transformers. I may say that during six years not one of the fifty odd transformers in Croydon has broken down due to repeated switching off and on. That they are all of the oil-cooled type may be partly responsible for this. Small punctures in the insulation, if they exist, may be filled up with oil before the transformers are again used. The oil, too, will act as a

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lubricant and prevent abrasion of the insulation due to vibration and alternate expansion and contraction. The mean temperature of the transformers is kept down by the practice of switching off transformers not required. With reference to the remarks on meters; in direct-current systems, ampere-hour meters of considerable capacity are obtainable which will record accurately on a 200-volt 5-c.p. lamp. If there are no very satisfactory alternating-current ampere-hour meters, it is possible to obtain accurate energy meters which require an exceedingly small shunt current and which have no moving contacts. Meters which require frequent inspection, cleaning, and adjusting cause more than half the trouble between the supply authorities and the consumers.

Mr. Addenbrooke has mentioned that the loss in a cable increases more than proportionately to the rise in voltage. We have found that to be the case; in fact, in some experiments we made, the increase has been more than proportionate to the square of the voltage. I am glad to hear that Mr. Addenbrooke also finds a considerable increase in the loss when the cable is surrounded by iron. Mr. Sparks mentioned the dangers of running up an alternator on a cable slowly. That is illustrated by curve 13, sheet C, in the paper. There we had an alternator running at about half speed under otherwise ordinary conditions on a cable, and the voltage rose to about 6,000 maximum on a 2,000-volt system.

I do not think any other points raised remain to be dealt with, and will therefore conclude my remarks by again thanking you for your kind reception of this paper.

[*Note added later.*—In all cases the C^2R loss due to the capacity current is included in the dielectric hysteresis loss, its value being only a small percentage of the total.]

Mr. Field.

Mr. M. B. FIELD (*in reply*):* I think the best way to answer the many remarks that have been made upon my paper will be to deal first with the more direct criticisms, and after that to cover with a few general remarks the further comments of other speakers. Referring first to Professor Hay, I certainly grant that to be lax with one's terminology is a most serious error for any one to fall into, and perhaps I am to a certain extent guilty in this respect, but I think that Professor Hay has rather exaggerated my delinquencies. First, with regard to the *secohm*. I suppose I should not defend the term, as it has now, by universal consent, been discarded, but it seems to me such a rational term, and "henry" seems anything but that. "Secohm" gives one at once an idea of what it is. Coefficient of self-induction may be said to be defined by the usual equation—

$$V = R C + L \frac{dC}{dt}$$

and is really the back E.M.F. in volts in a circuit when the current is altering at the rate of 1 amp. per sec. As regards its dimensions L is

* Mr. Field's reply to the discussion on his paper at Glasgow (see p. 694) is included here.

$V\left(\frac{d}{d}\right)\frac{t}{C}$ and therefore of the nature of a time multiplied by a voltage Mr. Field.
and divided by a current, hence the term sec-ohm.

Ohmic Resistance: The adjective "ohmic" may be superfluous, but no one can call it misleading. I use it to distinguish resistance-proper from "apparent" resistance, with which the paper deals considerably. I have referred to certain combinations of self-induction and capacity as behaving, as far as the external circuit is concerned, as a resistance of so many ohms. This is, of course, only an apparent resistance, as in most cases it is only true at one particular frequency that the combination could be exactly replaced by a resistance. In dealing with such combinations I maintain that it is not at all out of place to draw the distinction between resistance-proper and apparent resistance by applying the epithet "ohmic" to the former.

Self-induction of an Alternator: Professor Hay states I have used this term in more than one sense. I consider I have been most careful to explain the exact sense in which I have used it. I have pointed out what I consider the distinction between self-induction and armature reaction is. I have pointed out that an alternator cannot strictly be said to have any true coefficient of self-induction, as this depends on, and varies with, the saturation of the field-magnet system, the position of same relative to the armature coils, and the strength of the armature currents. I have pointed out the variable nature of this coefficient; I have then *for shortness* included in the term "self-induction" the effect of armature reaction, saying, "In talking of the self-induction of an alternator I shall, for the purpose of this paper, include in the term, armature reaction, *i.e.*, I shall refer to that self-induction (whether with constant or variable coefficient) which, inserted in series with a reactionless and self-inductionless machine, would give the same characteristics." Surely I cannot be blamed for indefiniteness here.

Synchronous Impedance: This is an American term. I think it implies what it is, viz., the impedance at synchronous speed. It includes self-induction and armature reaction, being determined by the comparison of the short-circuit armature current at synchronous speed at a given excitation, with the no load E.M.F. at same speed and excitation. The term is quite a well-known one.

I was somewhat surprised at the rather dogmatic way Professor Hay denied the correctness of the statement on page 662 that the combination (Fig. W.) behaves under *all* conditions, as far as the external circuit is concerned, as a resistance of r ohms provided $K = \frac{L}{r^2}$. The

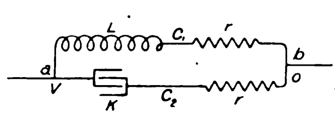


FIG. W.

text may be a little badly worded here, but when I say that this is true for all frequencies and for periodic and unperiodic functions, it is perfectly evident that the condition represented by (9) which refers to one particular frequency, has nothing to do with the matter. I did not attempt to prove my statement because the proof is to be found elsewhere. I thought it was a matter of common knowledge, for certainly Professor

Mr. Field. Perry has been in the habit of giving this case as an example to his students for fourteen or fifteen years. The proof is to be found on page 247 of Perry's "Calculus." This combination is, however, interesting from many points of view, and is worth study.

In the first place we see that if energy be stored either in the self-induction or the capacity, and this be allowed to discharge in the closed circuit, the combination is the critical one at which the discharge just ceases to be oscillatory.

Secondly, however V may vary, the total energy stored in the self-induction at every instant is equal to that stored in the capacity, for remembering $L = K r^2$ we may write, using Professor Perry's symbol θ—

$$V = r(1 + K r \theta) C_1$$
$$= \left(r + \frac{1}{K\theta}\right) C_2$$

The energy stored in the self-induction at any instant is $\frac{1}{2} L C_1^2$; and in the capacity $\frac{1}{2} K (V - r C_2)^2$. But it is clear that both these expressions may be written in the form $\frac{K}{2(1 + r K \theta)^2} . V^2$; hence, however V may have varied, the total energy stored at any instant as expressed by this formula is the same both for self-induction and capacity.

It is further interesting to note that if current be flowing through the combination from the external circuit so that a certain amount of energy is stored both in the self-induction and the capacity, on suddenly interrupting the external circuit, although the stored-up energy will discharge itself in the closed loop, there will be no difference of potential between the points *a* and *b*. Professor Gray has pointed out an error I have fallen into where, on page 668, I determine the coefficient of self-induction of an alternator (working under certain conditions) by taking the slope of the synchronous impedance curve.

I have really assumed that the equation $V = R C + L \frac{dC}{dt}$ still holds for a circuit containing iron (and therefore with a variable coefficient of self-induction) provided we express L in the above equation as a function of C. Professor Gray's criticism is quite justified. The true equation should be—

$$V = R C + \frac{d(L C)}{dt}$$
$$\text{or} \quad V = R C + L \frac{dC}{dt} + C \frac{dL}{dt}$$

that is to say, I have left out of account this last term. As, however, I have based no calculations on this, the drift of my argument is not affected.

Professor Carus-Wilson has found fault with some of my mathematics, asking whether the minus signs on page 691 in the expressions for V_0 should not be positive signs. Several of the professors have pointed out that the mathematics of the subjects treated in my paper have been worked out before. It is hardly necessary for me to say that I am perfectly aware of this, and have stated so myself in the

paper, and for this reason I have avoided mathematical treatment as far as possible. The theory of electric oscillations in capacity self-induction circuits was first worked out by Lord Kelvin between fifty and sixty years ago. In Part II. I have therefore merely stated the general differential equation which holds for such a circuit, and then given the particular solutions applicable to the cases experimentally investigated. (I have, it is true, as a slight digression, discussed briefly the characteristics of the damped oscillations, to remind those readers unfamiliar with the subject.) Professor Carus-Wilson has referred to Mr. C. P. Steinmetz's paper on this subject. My attention was called to this after my own was mostly written. Mr. Steinmetz in his admirable work treats the whole subject more as a mathematical problem. I must say I found the paper rather long and difficult, and the more important conclusions arrived at by making certain simplifications at the end of the work, I have tried to compass without the mathematics. With regard to Part III., Professor Carus-Wilson has referred to the work of Houston and Kennelly. These, of course, are not the only writers on this subject, *e.g.*, C. P. Steinmetz, Bedell, and Crehore, etc., and I think that the work of even these writers is to a certain extent an adaptation of Fourier to electrical problems similar to the heat problems treated mathematically by that physicist. Being again fully aware of this, I have satisfied myself with stating merely the general differential equations, and the particular solutions applicable to the case I am considering, viz., resonance at the end of a long unloaded three-phase cable, due to a high order of harmonic, which I have shown may exist in a practicable alternator, and my intention has been to arrive at the conclusion, by means of a numerical result, as to whether such resonance is likely to prove dangerous or not. Mr. Field.

Coming now to Professor Carus-Wilson's query *re* positive and negative signs, perhaps the best way will be for me to show here how the expressions in question are arrived at:—

The solutions given in the paper for v and c are (see page 689)—

$$v = V_1 \left[\epsilon^{-ax} \sin(2\pi n t - a x + \phi) + \epsilon^{-a(2l-x)} \sin(2\pi n t - a(2l - x) + \phi)\right]$$
$$c = \text{etc.}$$
$$a = \text{etc.} \qquad (1)$$

These equations can of course easily be verified by differentiation.

We see that when $x = l$, $c = o$, which is the condition of an unloaded cable; V_1 and ϕ are arbitrary constants, but if we say that at the beginning of the cable we will define the voltage as $V_0 \sin 2\pi n t$, we can find V_1 and ϕ as follows:—

Inserting in (1) $x = o$

$$V_0 \sin 2\pi n t = V_1 \left[\sin(2\pi n t + \phi) + \epsilon^{-2al} \sin(2\pi n t - 2al + \phi)\right]$$

Let $2\pi n t + \phi = o$, then

$$V_0 \sin \phi = V_1 \epsilon^{-2al} \sin 2al \qquad (2)$$

Let $2\pi n t + \phi = \frac{\pi}{2}$, then

$$V_0 \cos \phi = V_1 (1 + \epsilon^{-2al} \cos 2al) \qquad (3)$$

Mr. Field. Dividing (2) by (3) we have

$$\tan \phi = \frac{\epsilon^{-2al} \sin 2al}{1 + \epsilon^{-2al} \cos 2al}$$

Squaring (2) and (3), adding and taking the square root, we have

$$V_o = V_1 \sqrt{1 + \epsilon^{-4al} + 2\epsilon^{-2al} \cos 2al} \quad . \quad . \quad . \quad . \quad . \quad (4)$$

I then state that maximum resonance will occur when $a l = \frac{\pi}{2}$, the rise of voltage occurring at the free end of the cable. Inserting in (1) $x = l$, $l = \frac{\pi}{2a}$, we have as the voltage at the far end

$$2 V_1 \left[\epsilon^{-\frac{\pi}{2}\frac{\mathrm{a}}{a}} \sin\left(2\pi n t + \phi - \frac{\pi}{2}\right)\right]$$

the maximum value of which is

$$2 V_1 \epsilon^{-\frac{\pi}{2}\frac{\mathrm{a}}{a}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

combining (4) and (5), and remembering that $\frac{\mathrm{a}}{a} = \tan \theta$, we have the expression

$$\frac{2\epsilon^{-\frac{\pi}{2}\tan\theta}}{\sqrt{1 + \epsilon^{-2\pi \tan \theta} \boldsymbol{-} 2\epsilon^{-\pi \tan \theta}}} V_o \quad \text{or} \quad \frac{2\epsilon^{-\frac{\pi}{2}\tan\theta}}{1 \boldsymbol{-} \epsilon^{-\pi \tan \theta}} V_o \quad . \quad . \quad (6)$$

These are the expressions to which Professor Carus-Wilson objected, asking whether the minus sign which I have shown in thick type should not be positive. I would point out that whether this sign is positive or negative entirely depends on the term $\cos 2al$ in (4), and hence on the length of the cable under consideration. Where $l = \frac{\pi}{2a}$ the case here considered $\cos 2al = -1$, where $l = \frac{\pi}{a}$, $\cos 2al = +1$. This latter case, however, viz., where the length of the unloaded cable equals one half of the wave length is not a condition of resonance. With the correct length to give rise to resonance, the E.M.F. at the free end will be greatest when the copper resistance is smallest. If we assume this becomes vanishingly small, $\tan \theta = o$, and the voltage at the free end of the cable is for $l = \frac{\pi}{2a}$, infinity; and for $l = \frac{\pi}{a}$, V_o; that is, in this case, the voltage at both ends of the cable is the same.

This hypothetical case of a length of cable equal to one quarter wave length where the copper resistance is negligible is of great interest. Mr. Steinmetz has pointed out that at the one particular frequency it behaves as a constant potential to constant-current transformer, *i.e.*, if constant potential be maintained at one end, constant current will be given out at the other irrespective of the nature of the load (except, of course, in the case where the cable is an open circuit, when the potential rises to infinity, as above.) That this must be so is evident from the equations for v and c; for however the cable is loaded

the same form of expression holds for the current at one end of the cable as for the voltage at the other, and *vice versâ*, the coefficients only differing; hence if at one end the voltage be maintained constant, at the other end the current will remain so, and *vice versâ*.* Mr. Field

I do not altogether agree with Professor Carus-Wilson in supposing that this class of resonance will never be dangerous. Suppose an E.M.F. represented by the wave Curve XV. were applied to such a cable as I have assumed in my calculation, and the 13th harmonic were transformed up twelve times. At the far end of the cable the harmonic might quite easily be twice as important as the fundamental, in which case the maximum voltage would be nearly three times that of the fundamental.

Messrs. Constable and Fawssett in their excellent paper indicate that they expected to find a change of wave shape at different points along a fairly long cable, unloaded, upon which they experimented, and expressed surprise in failing to do so. I think myself that the length of cable necessary before any appreciable change would be observed is far beyond anything they have at Croydon. I do not think either that a change of frequency (within reason) would have created the expected variation as supposed.

In this connection I think it will not be altogether out of place here to give a comparatively simple graphical method for determining the current and voltage at any point of a long cable loaded on a more or less inductive circuit. Clearly we need only consider one harmonic or a sine function of E.M.F., for however complicated the applied E.M.F. may be, each term of the Fourier's series into which it can be expanded may be treated in like manner.

In the first place it is clear that the solution given on page 689 becomes for a loaded cable

$$v = \mathrm{V}'\epsilon^{-ax}\sin(2\pi n t - a x + \phi') + \mathrm{V}''\epsilon^{-a(2l-x)}\sin(2\pi n t - a(2l - x) + \phi'')$$

$$c = \frac{\mathrm{V}'}{\gamma}\epsilon^{-ax}\sin(2\pi n t - a x + \phi' + \theta) - \frac{\mathrm{V}''}{\gamma}\epsilon^{-a(2l-x)}\sin(2\pi n t - a(2l - x) + \phi'' + \theta)$$

where

$$\frac{1}{\gamma} = \frac{2\pi n\kappa}{\sqrt{a^2 + \alpha^2}} \quad \text{or} \quad \sqrt{2\pi n\frac{\kappa}{\mathrm{I}}}$$

* In this connection my brother, A. B. Field, has pointed out that the following combination of self-inductions and capacity acts as a constant potential to current transformer, provided it is loaded on a non-inductive load, and n is such that $2\pi n = \sqrt{\frac{1}{\mathrm{LK}}}$; the proof is simple; the combination is very interesting. I understand that Mr. Steinmetz first called attention to this combination.

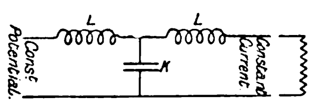


FIG. X.

Mr. Field. and where V', V'', ψ', ψ'' are determined by the terminal conditions—

$$x = o,\ v = V_o \sin 2\pi n t\ ;\ x = l,\ c = \frac{v_l}{\left(r + l\frac{d}{dt}\right)}$$

v_l being the value of v, obtained by putting in the value $x = l$, and r and l are the resistance and coefficient of self-induction of the circuit external to the cable, hereafter termed "the external circuit." Let the impedance of this circuit or $\sqrt{r^2 + 4\pi^2 n^2 l^2}$ be denoted by I'. We see that v and c consist each of an original and a reflected wave, and that the phase of each wave at any particular instant changes uniformly as we go along the cable. The difference of phase at two points separated by the distance x is ω where $\omega = a x$, whereas the ratio of the amplitudes at these points is $\epsilon^{\omega \tan \theta}$. If, now, we draw a logarithmic spiral, $r = \epsilon^{\omega \tan \theta}$ (see Fig. Y), of which the co-ordinates are r and ω, and say that the radius O a represents in magnitude and phase the original wave at the far end of the cable, then O b will represent the magnitude and phase at a distance x_1 from the end, where $\omega_1 = a x_1$. Similarly if O a' represent the reflected wave at the end of the cable, O b' will again be the phase and magnitude of the same at distance x_1 from end. The conditions which obtain at the end of the cable are these: Let O V, Fig. Z, be the voltage, and O c the current. I have shown these in two distinct diagrams for the sake of clearness, preferably they should be combined in one. O c = O V/I′ and cos χ is the power factor of the circuit supplied by the cable. Now O V is the resultant of two waves, say O d and O e; corresponding to each of these is a current wave, of which the amplitudes are O d/γ, O e/γ, and each is in advance of the corresponding potential wave by the angle θ. The resultant of O d and O e is O V, while the difference of the two corresponding current waves is O C. This is evident from the form of the equations v and c.

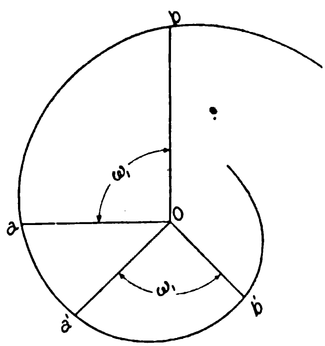


FIG. Y.

Draw a line O P, set back from O c by the angle θ. Bisect O V and draw through the centre a line parallel to O P of length O V . $\frac{\gamma}{I'}$, so that this vector is in its turn bisected by O V. Complete the parallelogram, of which these vectors are the diagonals, then O d, O e, represent the two voltage waves, because they give a resultant O V, and when we draw in the corresponding current waves in the current diagram, or O d', O e', these are such that (by construction) O d' − O e' = O c.

We have now only to superimpose the logarithmic spiral on the top of each diagram, rotate O d, O d' forwards through the angle ω' (= $a\,l$) and O e, O e' backwards through the same angle, increasing or decreasing the magnitudes of these vectors in proportion to the value of the polar

co-ordinate of the spiral, to find the values of the original and reflected voltage and current waves at the beginning of the cable. Taking the resultant of the two voltage vectors and equating this to $V_0 \sin 2\pi n t$ we fix the scale of the diagram, and the datum from which time is measured. For example, suppose $a l = \frac{\pi}{2}$ we rotate O d forward through a right angle and increase it in the proportion O s' : O s, we rotate O e backwards through a right angle and decrease it in the proportion O t' : O t. These two vectors represent the magnitude and phase of the original and reflected waves at the beginning of the cable. Their resultant is O V_0. Since the applied E.M.F. is $V_0 \sin 2\pi n t$ the length O V_0 represents the voltage V_0 which fixes the scale of the diagram, while all phase relations of currents, voltages, etc., are referable to O V_0. It is thus clear that by determining the values of the original and reflected waves and taking the sum or difference as the case may be, the true value of voltage and current at any point of the cable may be determined. Mr. Field

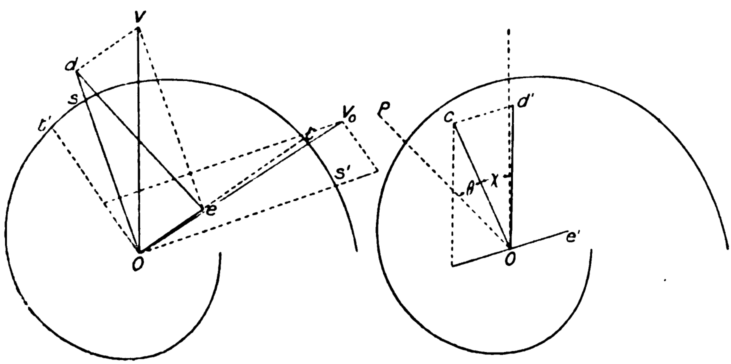


FIG. Z.

Professor Carus-Wilson asked for a further explanation of the footnote on page 688. I thought this was sufficiently clear. $\rho \lambda \kappa$ of Part III. have entirely different dimensions from R L K in II. The latter are resistance, self-induction, and capacity respectively, the former are the same physical quantities divided by a length, or resistance, self-induction, etc., *per unit length*. In Part II. $\sqrt{\frac{1}{LK}}$ is a frequency, or of the dimensions of T^{-1}; in Part III. $\sqrt{\frac{1}{\lambda K}}$ is a velocity or $\frac{\text{length}}{\text{time}}$; it was to keep this distinction clearly before us that I resorted to the Greek letters in Part III.

I do not agree with Professor Carus-Wilson in his remarks *re* the mis-application of the term resonance, nor do I think that Houston and Kennelly were the originators of the term. Resonance was known and understood in other branches of physics, vide Helmholtz's Resonators (accoustic), long before Houston and Kennelly's paper. One may say

Mr. Field. that the best definition of resonance is "Synchronism between the natural and forced vibrations of a system." With this definition the phenomena investigated in Part I. are true resonance effects. We are dealing with combinations of capacity and self-induction which have a definite periodic time of their own (natural vibrations), if now the frequency of the supply (or forced vibrations) correspond with the natural, we get serious magnification of the amplitude of the vibration or *resonance*. As another example, the periodic time of the vibrating portion of the oscillograph is say, $\frac{1}{10000}$th of a second, suppose we passed an oscillatory current of the same frequency through the strips we should have a case of mechanical resonance, the amplitude of vibration being largely in excess of that which would normally correspond to the current flowing. This is *resonance* in the strictest sense, and Professor Carus-Wilson is unduly limiting the use of the expression in restricting it only to such phenomena as are dealt with in Part III. In Part II. I grant it is hardly in order to apply the term "resonance" to the phenomena discussed, as there we are only dealing with the natural vibrations, but I have pointed out on page 682 that while in Part I. we have been dealing with cases wherein the frequency of the supply synchronised with the natural oscillations (or frequency of supply $= \frac{1}{2\pi}\sqrt{\frac{1}{LK}}$), in Part II. we are dealing *only* with the natural oscillation, the frequency of which is the same as the above, viz., $\frac{1}{2\pi}\sqrt{\frac{1}{LK}}$. We may almost consider the latter case as a particular instance of the former, where the amplitude of forced oscillation is zero. At any rate, the laws governing the two cases are so similar that I have classed the latter, though possibly incorrectly, as a resonance effect.

Professor Maclean (Glasgow) has contributed some very interesting remarks *re* harmonics present in some of the wave forms I have reproduced. It is quite evident that in a three-phase Y connected generator the 3rd, 6th, 9th, etc., harmonics can have no existence.* If, however, the voltage wave between one terminal and the neutral point had been reproduced (*i.e.*, of one leg of the winding only) I fully believe that traces of the 3rd, 9th, 15th, etc., would have been found.

I have pointed out that in such a generator the only harmonics which can exist (voltage being taken between two line wires) are given by the expression $6n \pm 1$, where n is any whole number. If we give n a value equal to the number of slots per pole per phase we get the two harmonics, which will in all probability be the most predominant. In the curves under examination we should expect to find only the 5th, 7th, 11th, 13th, 17th, 19th, etc. Similarly with regard to the ripple in the rotary D.C. E.M.F., as Mr. Hird has pointed out, the 5th and 7th will produce a ripple of six times the normal frequency, the 11th and 13th of twelve times, and so on; hence the order of ripples will always be a multiple of six.

* I have to thank Dr. J. B. Henderson of Glasgow University for first calling my attention to the fact that on theoretical grounds these harmonics must be non-existent in the alternators under discussion.

Mr. Field.

It is to be observed that since the 11th and 13th harmonics will both produce a ripple in the D.C. E.M.F. of the rotary of twelve times the normal frequency, these may either neutralise or augment each other. The cases are therefore possible that a large ripple may appear in the D.C. E.M.F. due to relatively small harmonics in the A.C. wave, or again, a perfectly straight D.C. E.M.F. line may result from an A.C. E.M.F. wave having considerable harmonics. The same thing of course applies to the other pairs of harmonics. Professor Maclean has drawn attention to the existence of a considerable 5th harmonic in certain wave forms. The somewhat rough and ready explanation I have given on page 657 of the cause of the existence of the 11th and 13th harmonics is based entirely on the number of teeth in the armature. I point out that there are twelve teeth per period, therefore we might expect twelve irregularities in the magnetic curve, hence the reason for considering the magnetic curve represented by $F N \sin k t + a (1 - \cos 12 k t)$, etc.; following out the argument of the paper it would of course have been incorrect to assume an expression such as $a (1 - \cos 6 k t)$ as Professor Maclean indicates. On the other hand, the existence of a pronounced 5th harmonic may very readily be imagined as due to the crowding together of the copper in the armature. It is quite conceivable that if the machine were a smooth-core alternator, but with the copper crowded together in the same way as in the actual case, a 5th harmonic might be the result. It is to be regretted that Professor Maclean had not time to continue his analysis of the curves published and determine in what proportion the 13th was present.

Coming now to Mr. Duddell's remarks, I would say in the first place that I am quite aware of his beautiful photographic contrivance for obtaining a continuous record from the oscillograph, but I could not use it on the score of expense. The makers quoted me something like £50 for the apparatus, and I understand that it is a comparatively easy matter to reel off £10 or £12 worth of films in a few minutes.

I therefore resorted to the dark slide shown in the paper; these cost me about 30s. a piece and ½d. per exposure. Of course, I was dealing with periodic effects, and those effects which were not really periodic I made periodic by employing the contact maker already described. I consider I obtained excellent results with my dark slides, and I can strongly recommend the use of the same for similar work. Where, however, it is desired to study such effects as those when arcs break out, etc., I admit there is no way of doing it satisfactorily except by the very expensive continuous film device.

Mr. Duddell referred to the effect on the A.C. voltage of a rotary, of sparking at the commutator, and stated that he would not like to say what might happen on account of resonance on the A.C. side should this sparking become bad. I have myself observed similar effects produced by sparking, not on a rotary, but at the contact breaker already referred to. I do not think, however, that this is likely to give rise to dangerous oscillations in the cable system. It appears to me that there is just as much likelihood of such effects occurring on the D.C. side as the A.C., and if they are serious, some such effect would have been

Mr. Field. noticed and recorded before this in connection with sparky D.C. generators which supply considerable cable networks. In the paper, however, I have called attention to the possibility of resonance with D.C. machines due to slight periodic voltage fluctuations corresponding to the number of armature slots or commutator segments, *e.g.*, compare ripples on Curve IV.; and although resonance under these circumstances would not probably assume any very great dimensions I think that in the case of rotary converters the effect due to the accentuated ripples in the D.C. voltage illustrated in the paper might become very serious.

Attention has been drawn by several speakers to the danger in running up a generator to full speed, when already excited and connected to a cable system. This is a point I attach considerable importance to and have dealt with myself in the paper. We did not appreciate the fact at first at all at Glasgow, but nevertheless noticed a curious effect during the process of starting up and shutting down. At a certain speed or speeds, as mentioned by my former assistant, Mr. S. Blackley, a kind of static sparking was observable between the live metal portions of the Westinghouse high-tension breakers into the wooden arms on which they were carried. It was afterwards found that these effects corresponded with the critical speeds at which partial resonance occurred.

Mr. Duddell referred at some length to the form factor; he attaches very great importance to the strain put upon the system due to a high form factor. In my paper I have said it is a mistake to attach too much importance to these effects, and to get frightened at them, though I most strongly urge the advisability of every engineer investigating fully what is going on inside his system so that he is in a position to appreciate and overcome any difficulties which may be introduced thereby. I may say, however, that at Glasgow, with the exception of the one isolated case above mentioned, there was nothing to indicate that anything abnormal was occurring at all. It was only because I expected to find deformations of wave shape from theoretical considerations that I was led to search for the results here published, and I may say that in some instances a very considerable amount of experimenting was necessary before I found the critical conditions.

When I was recently in the States I made a special point of asking central station engineers whether they experienced difficulties in working from these causes, and the almost invariable answer I received was that but for the theoretical writings of certain authors they would not know that such phenomena as resonance existed at all. Of course I know that certain stations over here have had considerable trouble with cables and apparatus, but nevertheless I am inclined to think that with modern up-to-date systems of cables and apparatus there is not much to fear. As regards form factor, even with a very distorted wave such as Curve XV., it does not exceed 2 or 2·2, whereas the form factor of a sine-wave is 1·4, *i.e.*, the maximum E.M.F. in the former case is only about 50 per cent. greater than in the latter, and if the insulation of the system won't stand this the sooner it breaks down and is taken out the better.

Another reason why I urge that too much importance should not be attached to the form factor is this: At the last meeting I indicated that unless very excessive voltages be applied there is strong probability that the determining factor as to whether an insulating material will break down or not is the heat developed per unit volume and the actual deterioration of the material thereby caused. If this be so, it is the R.M.S. of the voltage wave we have to consider and not the form factor. I do not wish to be misunderstood here; if it is a question of the insulation breaking down due to sparking across some air-gap or the like, I do not dispute that it is the form factor we have to look to, but what I mean is, if we consider a moderate excess of voltage which will not instantly break down the insulation, but after, say, 5 or 10 minutes, or even half an hour, then the primary cause of breakdown will probably be due to excessive local heating at the weakest spot, and in such a case a partial resonance producing a greater form factor is not serious provided it does not increase the R.M.S. value. I say this with considerable diffidence, and I'm afraid Mr. Duddell will not agree with me. I only wish that Mr. Duddell had written a paper on this subject instead of myself; he has made a large number of experiments and has a fund of information which *ought to be published* for the benefit of the electrical industry; I hope he will, in communicating his remarks to the Journal, expand them considerably and give us further details of his careful study of this most important subject. Mr. Field.

Major Cardew suggested that the assumptions made in the paper as to the suddenness with which a circuit is made or broken are untenable. He suggested that the switch itself had a certain variable amount of capacity which was really in series with the capacity of the cable, and on closing the switch this capacity was gradually reduced, thus gradually raising the potential of the cable before the circuit is actually closed. Now if we take the capacity of a ·2□″ cable, we find that it is about equivalent to that of two plates 750 sq. ft. area, or 28 feet square, separated by, say, $\frac{1}{8}''$. What can the capacity of the metal parts of the switch be in comparison with this? Probably not more than $\frac{1}{1000}$th part until the contacts came within striking distance, then a spark passes and the insulation of the air-gap being totally broken down, the circuit may be said to be closed instantly. Again, on opening a circuit Major Cardew suggested that the air arc which is formed and gradually lengthened causes the current to gradually die down. Now experiments show that this is very far from being the case. A high-tension air arc seems to finally extinguish itself with what might almost be termed explosive suddenness, even though it may have lasted several seconds previously. Whatever be the reason it has now been established beyond the region of doubt that the high-tension air arc is about the most vicious phenomenon possible in setting up high potential oscillations in the circuit. I admit that one would *naturally expect* the air arc to be equivalent to a gradual, and an arc under oil to an abrupt opening of the circuit. Oscillograph experiments show just the reverse. If a circuit be broken under oil there will be no high potential oscillations called into existence. As Professor Carus-Wilson has pointed out, this is of the greatest moment to engineers who have to deal with

Mr. Field. high-voltage machinery. The correctness of the above statements is beyond dispute, having been established by numerous experiments both in this country and in the States. It shows us at once that all apparatus such as switches, fuses, etc., where an arc can possibly form in air must be avoided in high-tension circuits, whereas oil switches and oil fuses may be used not only with certainty but without engendering the danger of high potential rises. I now wish to touch upon the matter of charging gear for cable networks. A good deal of correspondence has taken place in the electrical papers lately on this subject. It seems to have been the experience of some stations in this country that a main-charging gear is necessary. It is noteworthy that in the States I did not come across a single instance where one was installed. However, I would say, that if any engineer wishes one, let him have it by all means, but let it take the form of an absolutely non-inductive resistance. For this purpose a water resistance is manifestly correct. Anything in the nature of self-inductions, transformers, and the like, should be discarded as highly dangerous. Mr. Partridge has lately described an arrangement used at Deptford consisting of a transformer, the high-tension side of which is placed in series with the cable, and the low-tension side gradually short-circuited through a water resistance. This has apparently given satisfaction, and all I would say about it is, that Deptford has been very fortunate. The type of gear is certainly risky, at certain instants it introduces practically a pure self-induction in series with the capacity. It would appear that the values are such that the combination does not happen to be a dangerous one. We must remember that the Deptford wave form is a very nearly true sine-wave without ripples. If a number of different harmonics existed of any appreciable amplitude, it is clear that with the possible variations of capacity, self-induction, and slight variations of speed, resonance with one or other of the harmonics would be very likely to occur before long. Water resistance mains-charging gear can be made, in fact is made, entirely reliable, simple in operation, comparatively inexpensive, and by proper construction the insulation can be made as high as necessary. It is in fact thoroughly practicable, both mechanically and electrically.

With regard to applying high-voltage tests to cables, in my opinion a mediumly severe test for a long period, say 30 minutes, is preferable to a much higher voltage applied for only a few seconds. If a cable will stand a test for 30 minutes, it is very unlikely that it will be permanently damaged by the strain put upon it. If, however, a very high voltage be applied for five seconds, it is possible permanent damage may be done without actually breaking down the cable. It may stand for five seconds, but break down after ten. This means that deterioration is going on at some spot in the cable during those ten seconds, and consequently considerable deterioration (probably scorching as explained theretofore) may have already taken place at some spots during the first five seconds.

Mr. Atchison's communicated remarks are of great interest. I presume the alternator used was a comparatively small one ; I should judge somewhere in the neighbourhood of 5 kilowatts. Resonance

with the fifth harmonic required 27 m.f. capacity—this bears out the contention of the paper that under ordinary central station conditions resonance with low harmonics are not likely to occur, but only with the higher ones. I wish to thank Dr. Thornton and Professor Hay for the references they have given to previous experimental work on the subjects treated in this paper. Mr. Field

Mr. W. B. Hird's remarks have already been answered in this reply. I wish further to thank Dr. Henderson for the table he has worked out and appended, and lastly, to express my appreciation of the generous manner in which my paper has been received and discussed both in Glasgow and London.

The PRESIDENT: Gentlemen, I ask you to accord a most hearty vote of thanks to the authors for their papers. I am sure they have been most interesting in every way, while the discussion we have had has been particularly instructive, and really shows the value of the papers. The President.

The vote was carried by acclamation.

The PRESIDENT reported that the scrutineers announced that the following candidates had been duly elected:—

As Members.

Charles Orme Bastian.	Henry Sherman Loud.

As Associate Members.

Joseph John Perkins Barker.	James Geo. McLean.
Hermann Bohle.	James Mitchell-Cocks.
Frank William Davis.	Thomas Penrose.
John Walter Henry Hawes.	Philip Sydney Saunderson.
Alexander Percy MacAlister.	John Vincent.

Josiah Mower Wallwin.

As Associates.

Edward Coveney.	John H. Pennefeather.

As Students.

Hubert Henry Andrews.	Frederick William Halford.
Isaac Henry Becker.	Richard Pentony.
Randal Eugene Golden.	Kenneth John Thomson.

The Three Hundred and Ninety-third Ordinary General Meeting of the Institution was held at the Institution of Civil Engineers, Great George Street, Westminster, on Thursday, April 30th, 1903—Mr. ROBERT K. GRAY, President, in the chair.

The Minutes of the Ordinary General Meeting held on April 23, 1903, were read and confirmed.

The names of new candidates for election into the Institution were taken as read, and it was ordered that their names should be suspended in the Library.

The following list of transfers was published as having been approved by the Council:—

From the class of Associate Members to that of Members—

Randell Howard Fletcher.	Gerald Hart Jackson.
John H. C. Hewett.	Herbert William David Lewis.

Julius Leonard Fox Vogel.

From the class of Associates to that of Associate Members—

John Daniel Dyson.	William Fennell.

Francis William Hewitt.

From the class of Students to that of Associate Members—
Francis Powell Williams.

From the class of Students to that of Associates—
Arthur Blok.

Messrs. R. B. Hungerford and C. J. Phillips were appointed scrutineers of the ballot for the election of new members.

.Donations to the *Library* were announced as having been received from the Museo Civico, Como, and Mr. D. S. Munro; and to the *Building Fund* from Messrs. J. Grant and H. Owen, to whom the thanks of the meeting were duly accorded.

The CHAIRMAN: With reference to these donations, I may mention that the first is from the Museo Civico, of Como, who have sent for our Library a copy of a volume, with an illuminated cover, connected with what has been done by Volta. They also sent us eight copies for distribution at our discretion amongst various Libraries, and to-day the Council decided what should be done in distributing these. I mention this gift specially because it comes from a rather important body, and is a token of their regard for the members of the Institution who recently visited Italy.

I have to announce that the annual conversazione will take place on Tuesday, June 23rd, at the Natural History Museum, and that on June 11th a concert will be given. These dates have been selected because

there will be in London in June the Delegates of the International Telegraph Conference, and it was thought by your Council that it would be proper to give these gentlemen an opportunity of being present at the entertainments.

In front of me you will notice the shield which has been subscribed for by our students, and which is destined to be placed on the tomb of Volta at Camnago. I feel certain the members present will like to examine it; it is a work of art, and was designed for the students by Mr. Gilbert Bayes, a former art student at the Finsbury Technical College, a Gold Medalist of the Royal Academy School, and now instructor in modelling at Finsbury. I may remind you that a replica of this shield was deposited in the Volta Mausoleum, Camnago, by Mr. Hewitt, who represented our students. When the shield is affixed to Volta's tomb, the Museum of Como will be asked to receive the cast, which is now at Camnago. Within the next few days the shield will be forwarded to its destination.

The following paper was then read :—

DIVIDED MULTIPLE SWITCHBOARDS: AN EFFICIENT TELEPHONE SYSTEM FOR THE WORLD'S CAPITALS.

By W. AITKEN, Member.

The designing of an efficient telephone system for one of the great centres of industry requires much careful consideration, as the subject bristles with difficulties. The problem, however, is a most interesting one. Any system proposed must be as simple as possible, consistent with efficiency—quick, direct, reliable.

Before putting my suggestions before you it will be advisable to consider briefly the methods that have already been put forward.

The general practice has been to divide the area to be telephoned into sections, to place in each section an exchange, to connect the various exchanges together by direct junction wires where the traffic is considerable, and to connect the various exchanges or groups of exchanges also to one or more junction centrals, through which connections are obtained to small exchanges where the traffic is not sufficient to warrant direct junctions being run, so that complete intercommunication may be established. Figure 1 shows such an arrangement.

The weak spot of such a system is the multiplicity of junction calls. Only a small proportion of the total calls can be dealt with direct by one operator. In the larger exchanges 50 per cent. of the calls may be local, but in the majority of cases the percentage will be much smaller, in some cases only 5 or 10 per cent. Fifty to 95 per cent. of the calls have, therefore, to be handled by two—in some cases three—operators. The service is not, therefore, ideal. The call has to be passed from exchange to exchange, and a junction call takes about twice as long to complete as a local one.

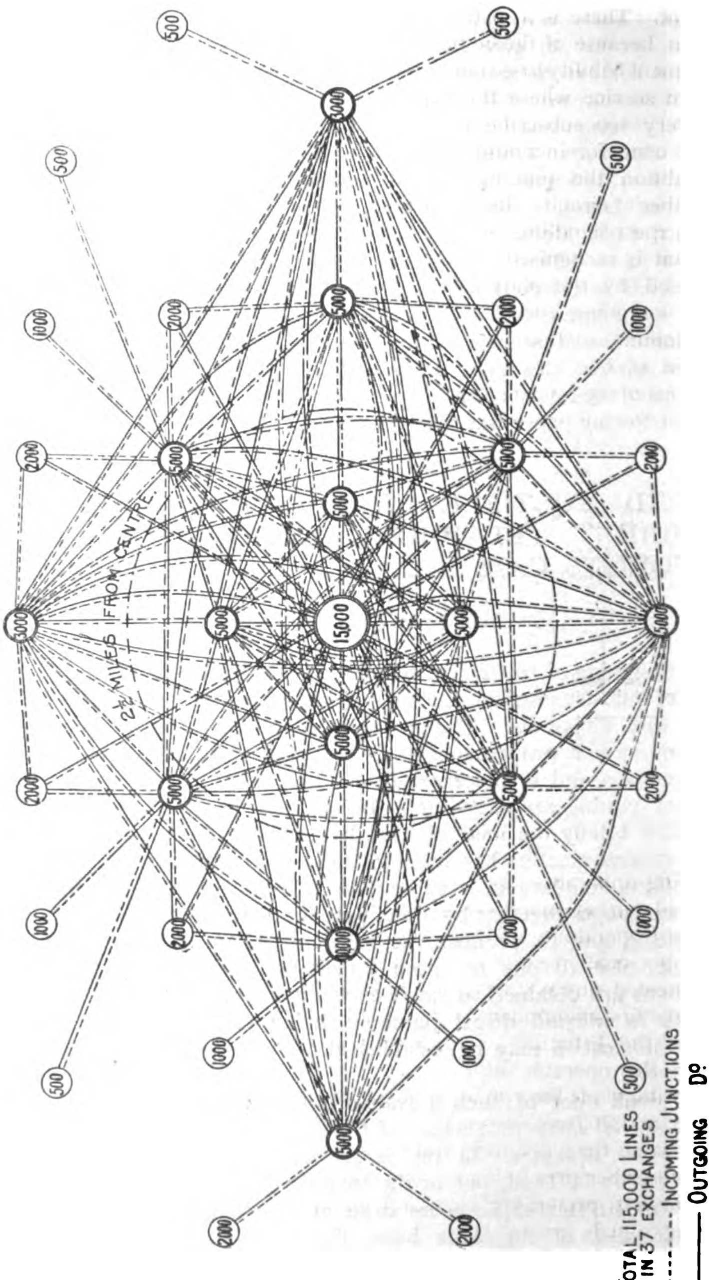

15,000
2½ MILES FROM CENTRE
TOTAL 115,000 LINES IN 37 EXCHANGES
---- INCOMING JUNCTIONS
—— OUTGOING Do

FIG. 1.

The subscriber's number has to be received by more than one operator. There is also the possibility of delay and inefficient transmission because of the complications of the junction circuits and their consequent liability to go out of order. In practice it is found that for an efficient service where there are a considerable number of exchanges, for every 100 subscribers' lines twenty junction lines are required, 10 per cent. for incoming work and 10 per cent. for outgoing work. In addition the junction circuit is much more complicated than a subscriber's circuit ; its apparatus is more intricate and requires more expert handling.

What is recognised as the best method of working junction lines, and used by the National Telephone Company, is as follows :—At the outgoing end the lines are multipled three times on every two sections, so that every operator has every line almost directly in front of her. At the incoming end the junctions are arranged in groups of 25 (average number) per operator and end in plugs, only

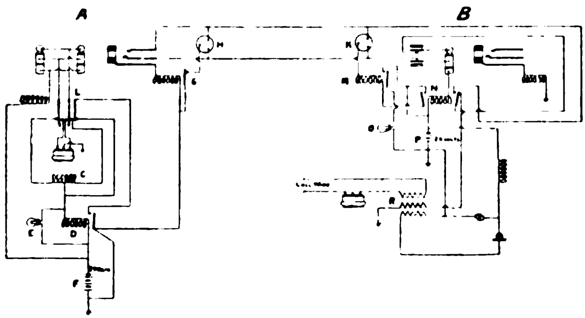


FIG. 2.

signalling apparatus being in addition. A service or order wire is provided per 25 junctions. This at the outgoing end is multipled on every operator's keyboard, and is connected to her telephone by pressing a small push-button. At the incoming end this service wire is connected direct to the operator's receiver. When a subscriber calls, the first-mentioned operator connects with the service wire and informs the listening operator at the other exchange the number wanted, this operator allots the junction to be used as she knows by the position of the plugs what lines are available, tests the line wanted, and, if free, inserts the junction plug, the originating operator at the same time connecting the subscriber to the junction specified. The subscriber may be rung by either the originating or the incoming operator but, preferably, by the latter and automatically. When the clearing signals are received from the subscribers by the originating operator she withdraws the plugs and automatically signals to the incoming end, the operator there then withdrawing the plug also.

The following is a description of two typical junction circuits :—

Relay Ring-through Junctions worked by Call Wire.

Fig. 2 shows the connections of a call wire junction line between two exchanges worked on the above system. This diagram should be considered in connection with Fig. 14.

At the outgoing end A, a local or subscriber's cord circuit is shown, L being the listening key, C the bridging coil, D the 250-ohm clearing relay with lamp E in parallel, and joined up so as to retain when pulled up by battery F.

A single tongued relay G is connected to the bush of the junction jack. The insertion of a calling plug into this jack operates relay G, and thus cuts the earth off the junction lines and bridging coil H.

The operator at the incoming end B obtains an engaged test through the tip of the junction plug and one outer tongue of relay N, on third conductor of the plug, through tertiary winding R of her induction coil. If there is no click she then plugs in, thus operating relay N, which disconnects the tip of the plug from the tertiary winding and connects it direct to the A line; this relay also joins clearing relay M (250 ohms resistance) from the centre point of retardation coil K, direct to earthed battery P.

The jack into which the junction line is plugged is that shown in Fig. 14. When the subscriber at the incoming end depresses his key, the clearing relay D (Fig. 2) at the outgoing end is brought up and retained, thus giving the clear at the outgoing end.

When the outgoing operator withdraws the calling plug from the junction jack, the relay G is released and puts earth on the centre point of the junction line, so that relay M is actuated and the clearing lamp O glows.

When the incoming operator withdraws the plug from the jack, the relay N is released and everything thus returned to the normal condition.

Central Battery Junctions Worked by Call Wire.

Fig. 3 shows the call wire circuit and also the outgoing and incoming ends of a junction. It will be noticed that at the outgoing end no relays are required to join up or cut off the clearing current, as this is already on the lines on the insertion of the plug *q*. (See Fig. 15.) The bush or test connection of the jack has a 30 ohms resistance coil joined in series to earth to complete the circuit for the supervising lamp on the calling plug. The call wire is brought through a key so connected that adjacent positions may be joined together, and terminates on the operator's instrument. A self-restoring indicator relay is also bridged on the line for night use, in the night bell contact of which is joined a lamp, battery and relay for calling when the operator is not listening, a special key being fitted to restore the indicator. In this system also no listening or testing keys are used, these being replaced by a relay C in the third conductor of the cord, and an induction coil with three windings connected so that in the normal position the tip of the plug is joined to the tertiary winding ready to

receive the engaged click, and on the insertion of the plug the relay is actuated and the tip is broken from the induction coil and connected through to the line. This relay is also in circuit with the clearing lamp which is 12 volts and has resistances placed in series with it.

In this circuit a ringing control is used. When the key is depressed

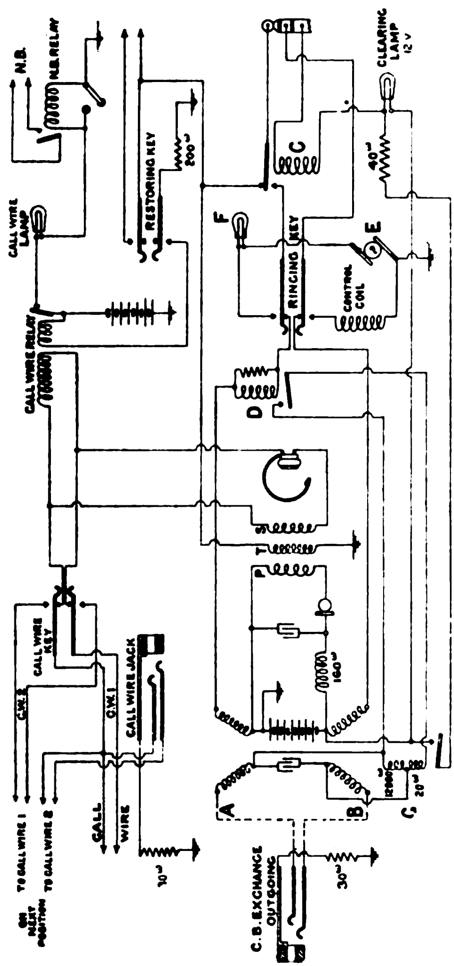


FIG. 3.

a clutch holds it in that position and connects up the ringing generator. When the telephone is taken from its rest an excess of current actuates the electromagnet and releases the clutch, thus cutting off the generator. The only other special point in this circuit is the method employed for clearing, so that on the called subscriber replacing his telephone the clearing signal may be given right back to the calling plug circuit at

the originating exchange, and on this plug being withdrawn the clearing lamp in the incoming junction plug circuit glows.

This is accomplished by means of a special relay G having two windings, one of very high resistance (12,000 ohms), so that the supervising relay on the calling plug at the originating end will not be actuated through it. The other coil is of low resistance to hold up the armature of the relay. This keeps the clearing lamp out by shunting it with a 40-ohm coil. The high resistance coil of relay *g* is short-circuited by the armature of the supervisory relay D in order that the line resistance may be reduced to a minimum, so that the supervisory relay on the calling plug at the outgoing end may be actuated and

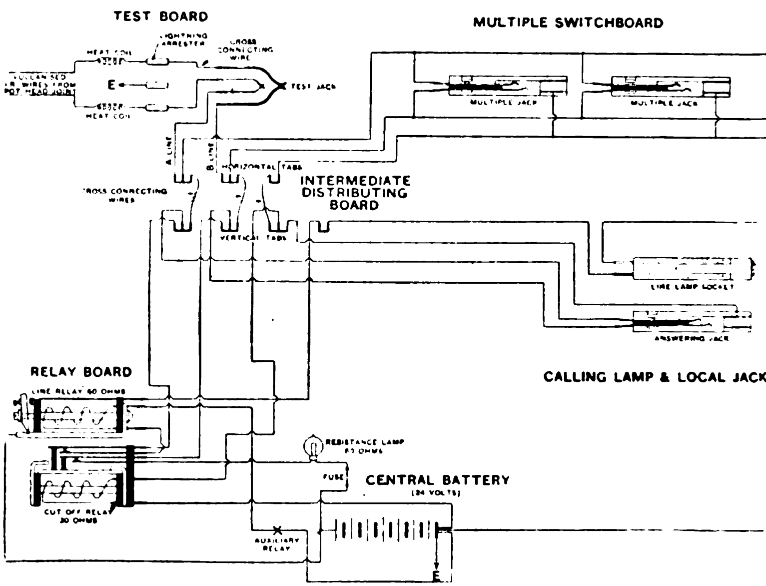


FIG. 4.

so keep the clearing lamp on that plug out while the junction is engaged.

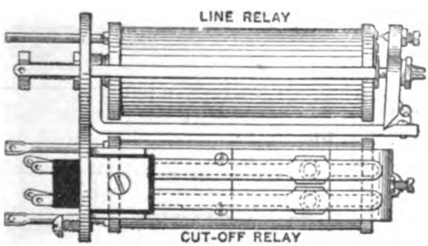
It will thus be seen that when the local subscriber on the incoming junction has finished his conversation and replaces his receiver on the rest, the circuit is broken and the armature of the supervisory relay D falls back, and the high resistance coil of relay G is placed in circuit in the line. This releases the supervisory relay on the calling plug at the originating end and causes the corresponding lamp to glow. The high resistance coil of relay G is, however, during this time still keeping its armature attracted, but on the withdrawal of the calling plug at the outgoing end this is released as the current is cut off, and the lamp glows, giving the signal to clear.

The condenser placed in the line side of the repeating coil is used

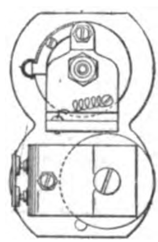
to improve the talking, otherwise the choking effect of relay G would make speech impracticable.

We will just glance for a moment at the circuits of an up-to-date Exchange—on the Common Battery System—so that you may appreciate the slight additional complications which are made necessary by the divided system to be described. Fig. 4 shows the line circuit of the Western Electric Company's system. Fig. 5 shows the line and cut off relays in detail.

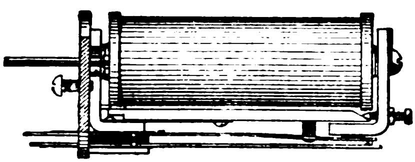
In such a system all lines are multipled on every section of switchboard, each containing about 300 subscribers' lines served by three operators. The multiple and answering jacks are branched from opposite sides of the intermediate distributing board. A line and cut off relay is in combination with each line. The subscriber's instrument has a con-



Side Elevation



Front Elevation



Plan of Lower (Cut-off) Relay

FIG. 5.

denser in circuit with the bell normally, which prevents the centra battery discharging. When a call is made by taking the telephone from its rest, a path is provided for the current through the microphone and induction coil, and the line relay is energised. The calling lamp in the local circuit glows, and the operator answers by inserting a plug into the jack hole immediately above the lamp. The cut off relay is then energised and cuts the line relay out of circuit so that the calling lamp ceases to glow. The connection is completed by the insertion of the other plug of the same cord into the multiple jack of the line wanted. A skeleton cord circuit is shown in Fig. 15.

The line and cord circuit of the Kellogg Switchboard and Supply Company are shown in Figs. 6 and 7. The peculiarity of this line circuit is that there are only two wires throughout the switchboard per line instead of three as is usual, and that the lines are not connected to the multiple until the plug is inserted. The cut off relay coil is tapped off the line circuit instead of being on the third wire. The

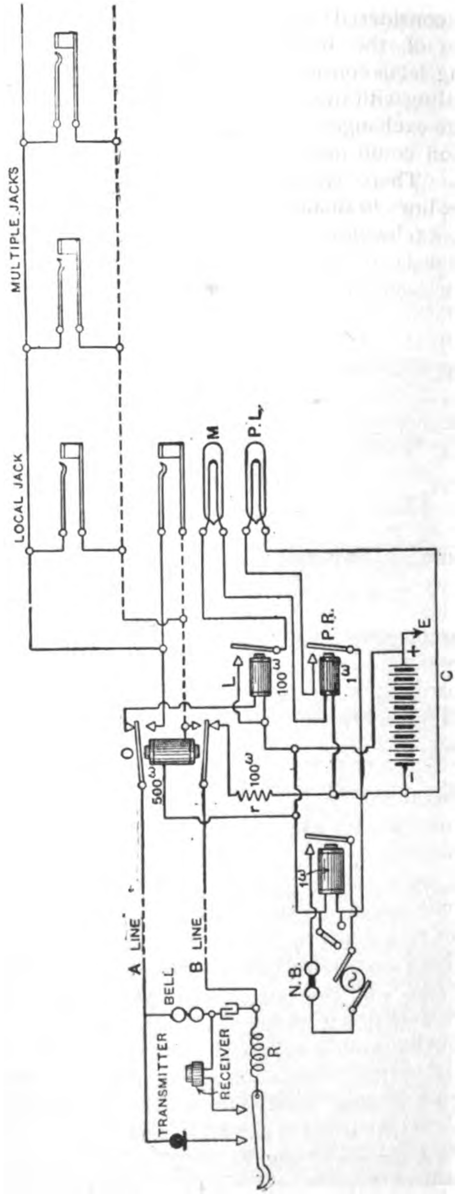


FIG. 6.

NOTE.—The blocks of Figs. 4, 5, 6, 7, 8, were kindly lent by the *Electrician*.

cut off relay is shown in detail on Fig. 8.

Having now considered the general principles of the usual methods of working, let us consider a concrete case, dealing with an area served by two large exchanges.

Such a condition could hardly exist in practice. There would almost certainly be lines to smaller and more distant exchanges. In large systems it is usual to reckon the number of junctions necessary at 20 per cent. of the number of subscribers' lines in an exchange.

In considering the following hypothetical case, I have calculated on 15 per cent. being necessary for working between two large exchanges.

Between two exchanges of 10,000 lines each 15 per cent. of junction lines would be required, $7\frac{1}{2}$ for incoming work to one exchange and $7\frac{1}{2}$ to the other, or 1,500 metallic circuit lines. To accommodate the incoming junctions 20 switchboards (10 in each exchange) would be necessary with 25 lines per operator and three operators' positions per board. Sixty operators and six supervisors are, therefore, required to work the incoming junction lines in the two exchanges, and as each subscriber's operator has a large proportion of connections for the other exchange she cannot attend to so many calls as she could do if all the work were local. On each junction switchboard the complete multiple of 10,000 subscribers' lines must be repeated, and on every subscriber's section 1,125 spring jacks must be multipled for out-going work to the other exchange, these being multipled three times on two sections to place them well within the reach of the operators.

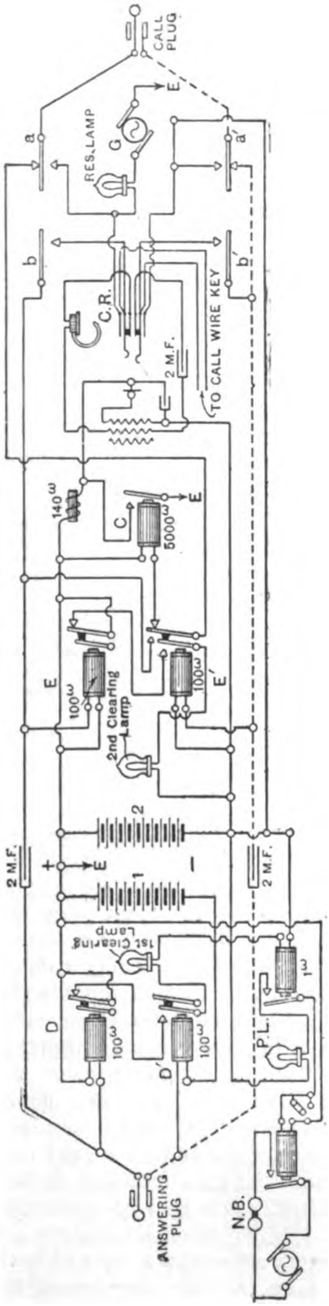


FIG. 7.

The provision of junctions between exchanges is a difficult one, for to provide an ideal service the number of circuits must be sufficient to carry the maximum number of calls at the busiest half-hour of the busiest day, and necessarily many of these junction circuits would be lying idle the greater part of the time.

In the earlier days of telephony there was not much need for the divided board, as the great cities were efficiently telephoned with switchboards having a capacity of from 6,000 to 15,000 lines. When necessary a number of these were fitted and connected by junction lines. Even to-day the system I advocate is worthy of consideration practically only in the world's capitals, where it may be expected that the number of telephone subscribers may reach something like 100,000.

Underground work is essential with the divided board, owing to

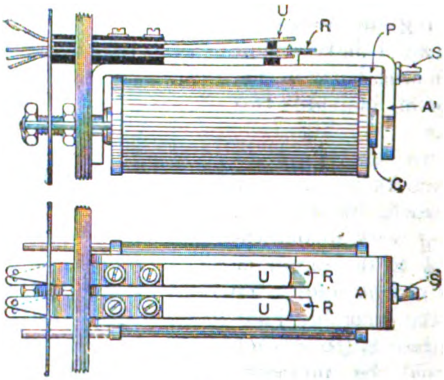


FIG. 8.

earths, etc., giving false calls, and it is only of late years that facilities could be obtained for work of such a nature, and even to-day way-leave facilities are not always obtainable.

It is only in recent years also that satisfactory conduits for large capacities have been introduced, and that hermetically sealed lead-covered air-space paper cables containing a large number of conductors were manufactured. The system I am about to describe to you is just beyond the experimental stage, and I think the time is now ripe for it to receive careful attention.

Such a system must, of necessity, be an underground metallic circuit system. The average length of subscribers' lines would be greater with a divided system than with the junction system, as a larger area would be served from a central, but against this must be placed the great reduction in the number of long junction circuits with their elaborate switchboard equipment.

In my opinion, it is only by adopting a divided multiple switchboard system of working, in which the exchange is divided into several sections, the subscriber having the power to call any one of the sections at will, the large cities of the world may be more efficiently telephoned.

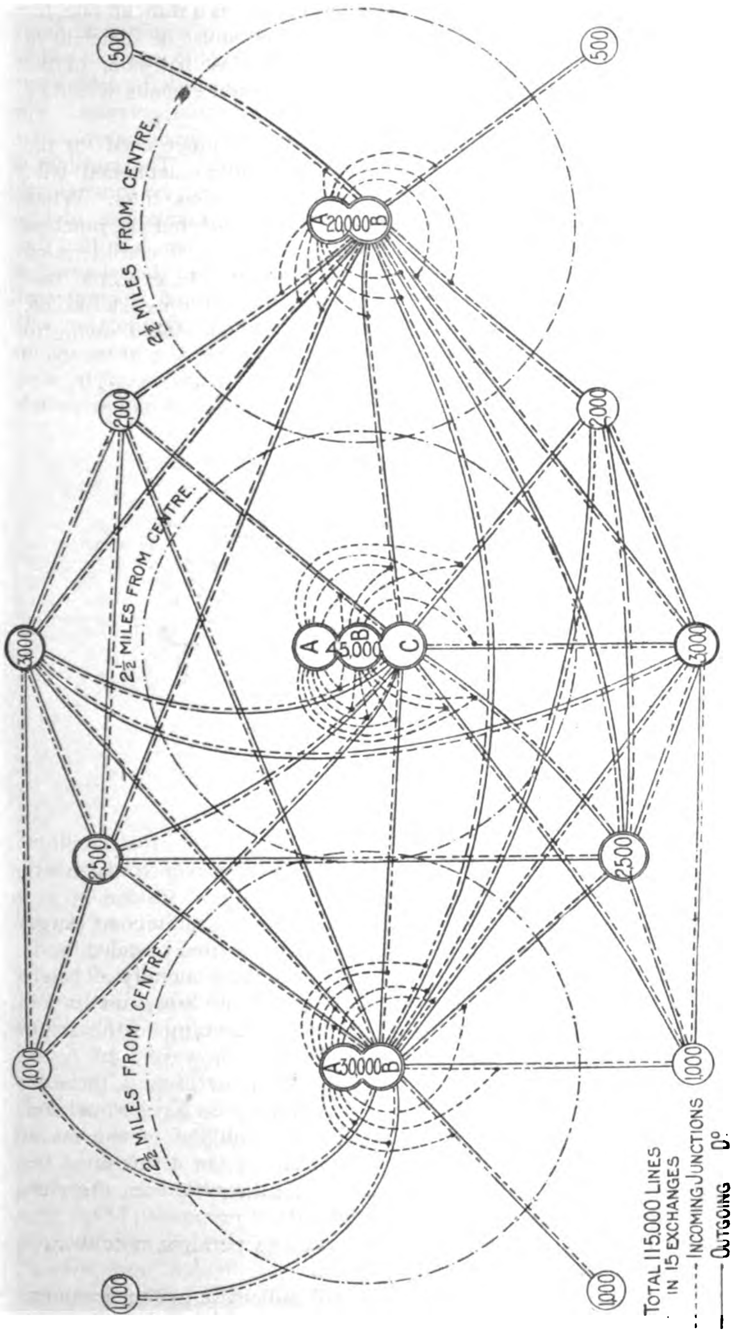

500
A 20,000 B
2½ MILES FROM CENTRE.
2000
3000
A 45,000 B C
2500
A 30,000 B
1,000
1000
TOTAL 115,000 LINES
IN 15 EXCHANGES
INCOMING JUNCTIONS
OUTGOING Do

FIG. 9.

By a divided multiple exchange, I mean an exchange divided into two or more groups, each group having a multiple of a proportion only of the total subscribers' lines, each subscriber having the power of calling each of the groups at will and obtaining connection with the subscribers multipled thereon without the intervention of a second operator. The advocates of the divided multiple board system believe in centralisation and the abolition of junction lines as far as possible. The multiple of each switchboard or division is made as large as can be conveniently reached by the operator, and where those who favour the divided system differ from the advocates of the junction system is in that they ask the co-operation of the subscriber by giving him the selecting of the group of switchboards on which the line wanted is connected. Two or three push-buttons or switches are fitted in combination with the ordinary subscriber's instrument, one, say, labelled 1 to 10,000, the second 10,001 to 20,000, and the third 20,001 to 30,000, or in other suitable divisions. In addition to taking the telephone from the switch-

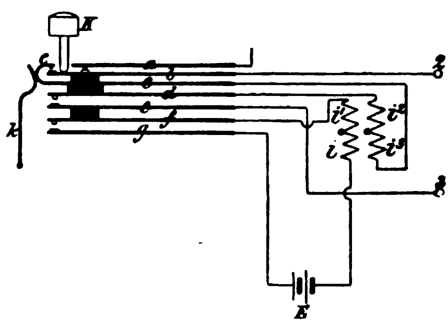


FIG. 10.

hook the subscriber has to press the button of the group in which is the number required; he then gets the connection direct instead of as in the junction system, the first operator having to ask the second to assist her in completing the connection in a large proportion of the calls.

The central exchange on a divided system consists really of two or more great multiple switchboards serving a large area, and its total capacity may be from 30,000 to 60,000 lines, according to the size of the units and number of divisions. Instead, however, of having junction lines between the exchanges the subscriber's line is branched to each division and has a calling signal and answering jack on each, so that it can be connected to each of the multiples of the several divisions, his own line being multipled on one of the divisions so that other lines may be connected to it. The subscriber can, therefore, greatly expedite the rate of operating for a great proportion of his calls, and at the same time he enables the operator to perform more work as a second operator more rarely intervenes.

A proportion of junction working will still exist to the exchanges more distant from the centre, but in most instances it will be possible

to so design a system that 75 per cent. of the possible junction working will be eliminated. I have, therefore, based my estimates on this figure.

Fig. 1 shows a large populous area telephoned on the junction

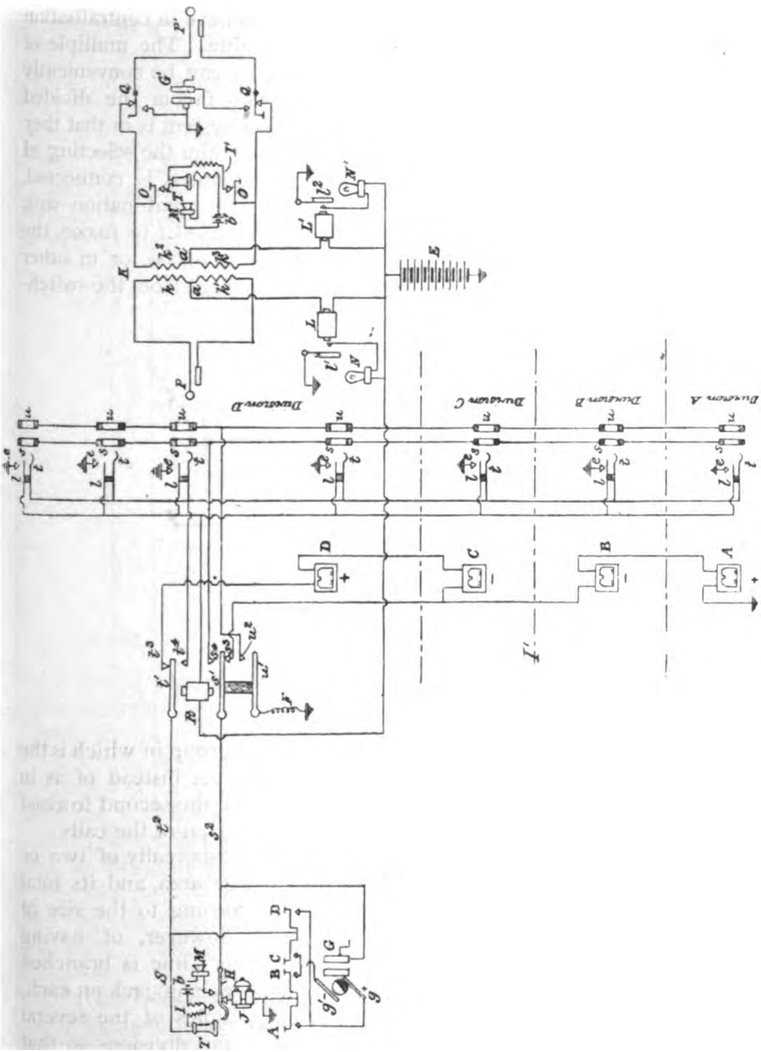


FIG. II.

system, the total number of subscribers being 115,000 in thirty-seven exchanges. The largest exchange has a capacity for 15,000 lines, or 13 per cent. of the total. In the two largest exchanges there is 22 per cent. and in three 26 per cent. Even if the three exchanges were each of 15,000 lines they would only contain 39 per cent. of the whole.

Fig. 9 shows the same area telephoned on the divided multiple system for the same number of lines in fifteen exchanges. The largest exchange has 45,000 lines and the next 30,000 lines. In the former there is 39 per cent., in the two 65 per cent., and in three 83 per cent. of the total.

The lines on the diagrams indicate direction only and not the number of circuits necessary.

I may be accused, with a good deal of justice, of comparing a

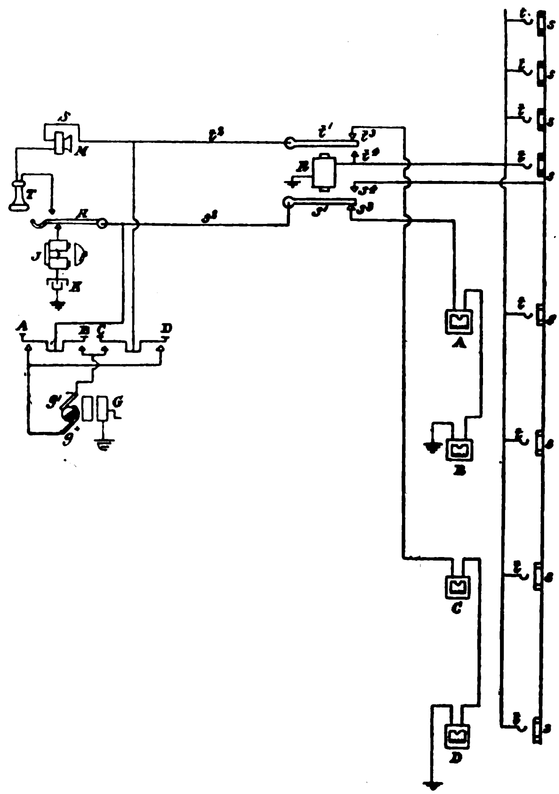


FIG. 12

theoretically good divided system (Fig. 9) with an imperfect junction system (Fig. 1), but with the latter system local conditions and limitations, such as rivers, public parks, low-class residential neighbourhood, etc., form natural boundaries beyond which for the sake of economical working it is not desirable to extend, and therefore single exchanges of the maximum size are not always possible or essential, whereas this does not apply to the same extent to the former.

Milo G. Kellogg, of Chicago, was, I believe, the first to design and advocate a divided multiple board system, and a number of exchanges

are now working in America on this plan. Usually two divisions have been adopted, but in one or more cases a four division board has been installed. In these pioneer exchanges the system was complicated by polarised relays and indicators on the switchboards, and at the subscribers' offices by commutated magneto generators.

In at least one case the magneto generators were replaced by the primary speaking battery, acting through an induction coil, giving a "kick" when the circuit was made and broken, sufficient to energise the calling signal (see Fig. 10). Suitable switches connected the current generating apparatus to line in the proper direction to actuate the signalling apparatus in the division required.

In one circuit a positive and a negative polarised indicator are in series across the loop and two similar indicators in series are connected as a tap to earth on one wire of the metallic circuit. (See Fig. 11.)

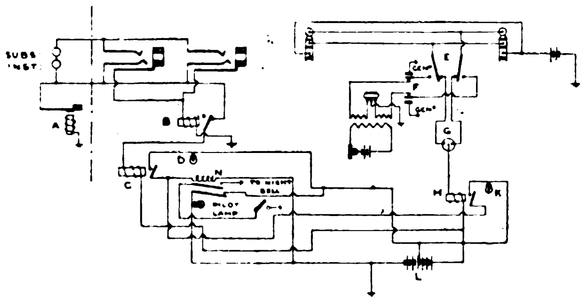


Fig. 13.

In another case a positive and a negative polarised indicator are in series and tapped to earth, two off each line. (See Fig. 12.) Four-division exchanges are thus obtained.

With the development of the central or common battery system of telephone exchange working and the popularising of the telephone the need for a simpler way of working great central exchanges became more urgent, and when considering this question I was struck with the idea of working a divided system from a central battery. I had previously designed two circuits which led naturally up to this, one in February, 1898, with a retaining electromagnet at the subscribers' instrument, which allowed a momentary depression of a key (thereby mechanically completing the circuit of the central battery through the calling relay to earth) to give a permanent signal to the operator (Fig. 13) and another in June, 1899, in which I removed the electromagnet from the subscribers' instrument and provided a local retaining circuit on the relay at the exchange, utilising the ordinary line relay coil for this purpose (Fig. 14).

The latter I preferred to use for my divided board system, as it simplified the apparatus at the substation.

In this system non-polarised relays are used, energised from a central battery when any one of the simple switches at the substation

RING THROUGH SYSTEM

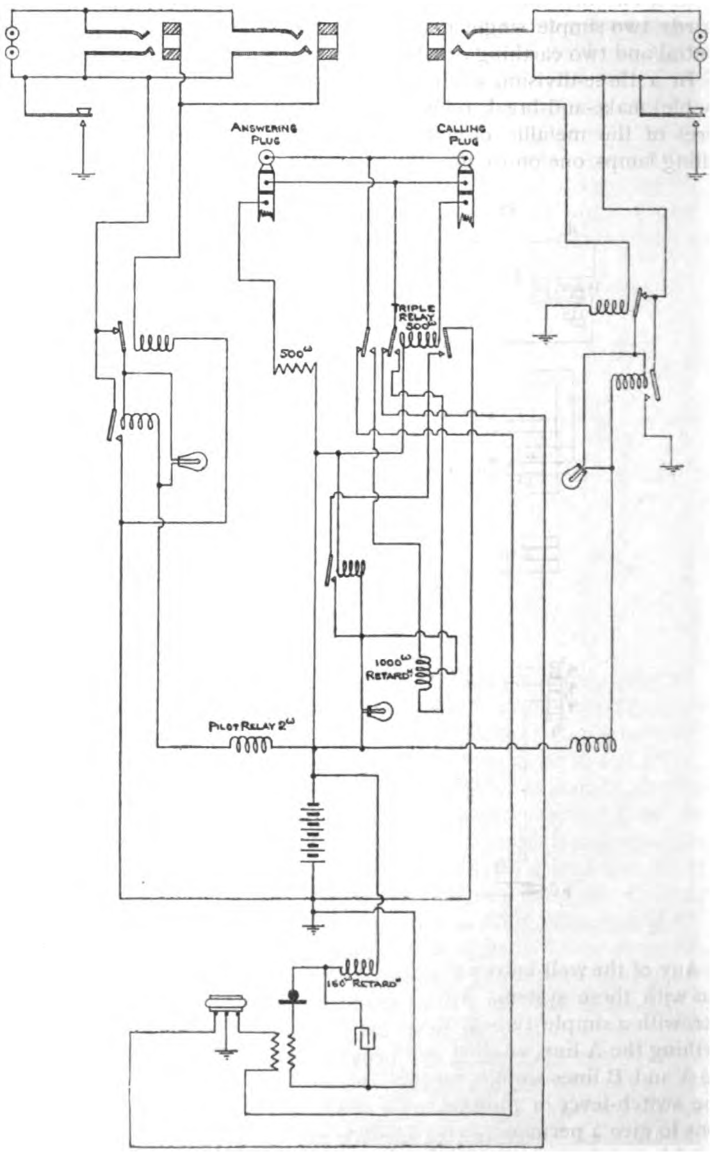


FIG. 14.

instrument is depressed. The caller can thus select any one of two or three groups of multiple switchboards required.

A greater number of combinations could, no doubt, be obtained by step by step movements, but at the expense of simplicity.

In a two-division exchange having two groups of multiple switchboards, two simple single make-and-break relays are necessary at the central and two earthing or grounding switches at the substation.

In a three-division exchange two double (or one triple and one double) make-and-break relays are used in connection with the two wires of the metallic circuit, and in connection with them are three calling lamps, one on each of three groups of multiple switchboards.

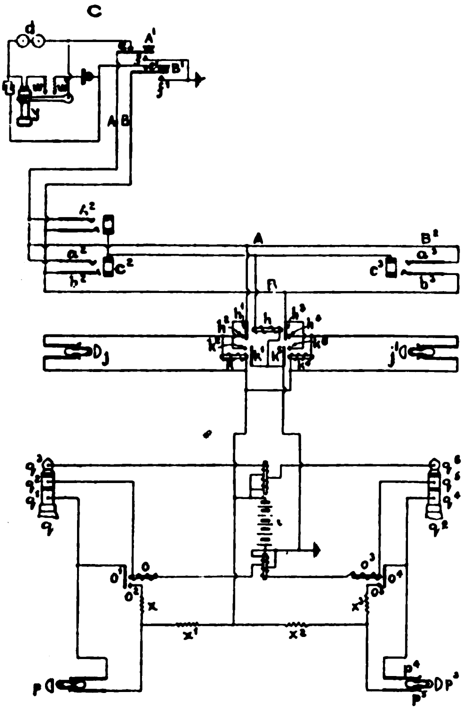


FIG. 15.

Any of the well-known forms of instruments may be used in conjunction with these systems, it being only necessary to fit in combination therewith a simple two- or three-way switch as required, one position earthing the A line, another earthing the B line, and the third earthing the A and B lines simultaneously (the latter in the three-division only). The switch-lever or plunger is put momentarily in one of these positions to give a permanent signal to the attendant at the corresponding switchboard.

With a two-division system, shown in skeleton on Fig. 15 and the line-circuit in more detail on Fig. 16, two switchboards, A^2, B^2 (Fig. 15),

of suitable size are provided, and one-half the total capacity is multipled on one line of boards and half on the other. Each subscriber's instrument has two push-buttons, A^1, B^1, one for earthing the A and the other for earthing the B line.

Each line, after passing through the usual test-board or main distributing frame, T.B. (Fig. 16), is connected to a special double intermediate distributing frame, I.D.B. To a central set of soldering tabs the two test-board wires are connected, and from the same set a triple wire per circuit is carried to the multiple jacks, M.J., of one line of boards. From a parallel strip of tabs on one side of the central line tabs a quadruple wire per circuit is carried to the answering jack, A.J.^{1}, and calling lamp, C.L.^{1}, on the same line of boards and from a parallel line of tabs on the other side of the central line tabs another quadruple wire per circuit is carried to an answering jack, A.J.^{2}, and calling lamp, C.L.^{2}, on the second line of board. A quad-cross-connecting wire connects the central line tabs and the tabs on both sides. All wires from the intermediate frames are made up in cables, but the wires between tabs are made in loose quads to allow of ready alteration with the object of changing the local position of any subscriber so as to equalise the work per operator, as in this arrangement it is necessary to allow distribution on each line of boards. Each quad is made up of the two line wires, the test wire and a lamp wire. The test wire also has a connection through the cut-off relay coil to earth. Each line wire has a connection through a tongue and contact of the cut-off relay, C.O.R., and its line relay coil, L.R.^{1} or L.R.^{2}, to battery and earth. Each tongue of the cut-off relay, C.O.R., has also a connection to the tongue of the line relay associated with it, the under-contact of each line relay being connected to earth.

The answering jacks and calling lamps are arranged in the usual way, with pilot relay, P.R., and lamp, P.L., night-bell, N.B., etc., as shown at Fig. 16. The calling lamp has also a connection to the line side of the relay coil, so that it is in parallel with that coil. The action is as follows:—

When a subscriber depresses key A^1 (Fig. 15) there is a circuit from the earthed central battery through line coil of relay, k (with lamp, j, in parallel) associated with that line, through one contact and tongue of cut-off relay, h, through the A wire to earth at key A^1. The line relay, k, is therefore energised and the lamp, j, glows. There is then a local circuit from earthed central battery through line coil, k, and lamp, j, in parallel, through contact and tongue of cut-off relay, h, through tongue and contact of line relay, k, to earth, and the lamp, therefore, continues to glow after the key A^1 is released until the operator answers. This is done by inserting a plug, q, of a connection set into the answering jack, C^2. Another local circuit is then established from earthed central battery, i, through the shunted lamp, p, on the third conductor of the cord to sleeve of plug, q, bush of jack, C^2, over test wire, through cut-off relay coil, h, to earth. The cut-off relay, h, is, therefore, energised and the line relay circuit broken by the tongue leaving the outer contact, so that the calling lamp ceases to glow. The subscriber may then be connected with any other on that

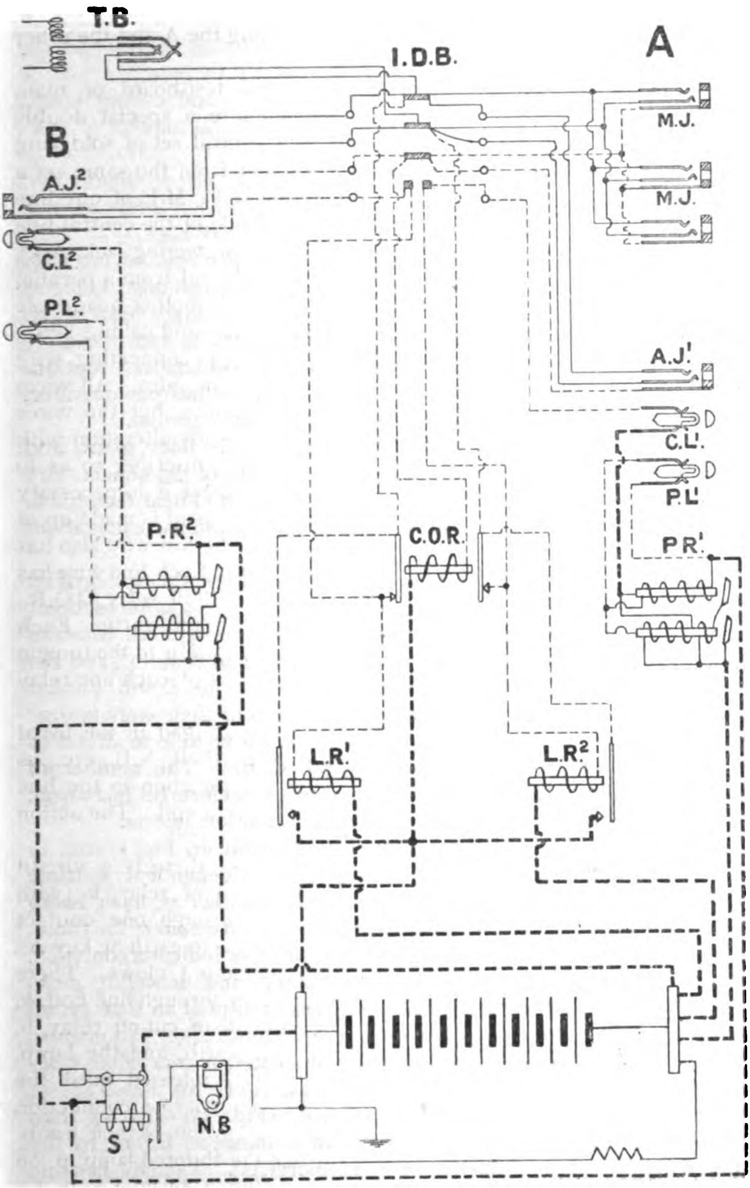


FIG. 16,

multiple. Should the B^1 key be depressed, the other line relay and lamp will be energised, the retaining circuit be broken by the cut-off relay being energised by a connecting set used by an operator at the second line of boards, and a connection completed thereon.

Each operator may have 300 answering jacks and calling lamps under her control, but will only attend to half the total number of calls from each subscriber.

As there are fewer junction lines between exchanges on the divided system, the outgoing junction work will be less and each local operator will therefore be able to attend to a greater number of lines.

Presumably on the junction system about 50 per cent. of the calls would be for the second exchange, and as a junction call takes twice as long to complete as a local one, if most of the work is made local, as on the divided system, the operator will be able to attend to approximately 50 per cent. more lines, so that instead of $66^2/3$ subscribers' sections being necessary on the junction system at 100 lines per operator, only $44^1/3$ sections would be necessary on the divided system.

There will also be a very considerable saving in floor space, and consequently rent or value of premises, as the length of the unnecessary junction and subscribers' sections would be about 270 lineal feet, made up of 20 junction sections and 22 subscribers' sections, each about 6 ft. 6 in. long.

If three 10,000 line exchanges were opened on the junction system then possibly treble the number of junction lines, multiple junction sections, and operators would be necessary, as 1,500 lines are required between A and B, 1,500 between B and C, and 1,500 between A and C, and the subscribers' (or local) operators can each attend to a still smaller number of calls, because a still greater proportion of their work is over junction lines, and each local operator would then be able to attend to a smaller number of lines, say 90 instead of 100. The number of switchboards and number of operators would therefore be increased, while there would be no increase on the three-division system.

With a three-division system, shown in skeleton on Fig. 17 and in detail on Fig. 18, at the central exchange three independent multiple switchboards are fitted, one-third of the total number of lines being multipled on each. Each subscriber's line is multipled on *one* of the three, but has an answering jack and calling lamp (or other indicator) on each. An operator may therefore have 450 calling lamps and answering jacks to attend to—150 in connection with the lines multipled on that group of switchboards and 150 each in connection with the other two groups, so that the subscribers can call and be connected to the other lines that are multipled thereon. Three relays, as before, are required for each circuit, one—the cut-off relay, C.O.R. (Fig. 18)—having two springs which are made to break from two contacts, as before, by the action of the armature when the relay is energised. The coil has one side connected to the earthed side of the central battery and the other side connected to the test circuit of the spring jacks, as is usual. The two line relays differ from those of the two-division board and more nearly resemble the cut-off relay. One has two springs which break from one and make on two contacts when energised, the other has

three springs which break from one and make on two contacts when energised. This modification from Fig. 17 was necessary to get a common circuit from pilot relay, P.R.[3].

The coil of each line relay, L.R., has one side connected to the earthed central battery, the other side being connected to the outer contacts of the cut-off relay, C.O.R. The relay tongues or moving springs of the cut-off relay are connected one to each line, each also having parallel extensions to one of the tongues of its respective line relay; these tongues, when the relays are energised, make contact with inner points connected to the earthed side of the central battery. A small incandescent lamp, C.L.[1], connected with the No. 1, or A, group of boards is in parallel with the coil of one-line relay, L.R.[2], and a second lamp, C.L.[2], in connection with the No. 2, or B, group of boards, in parallel with the coil of the other line relay, L.R.[1]. The line relays

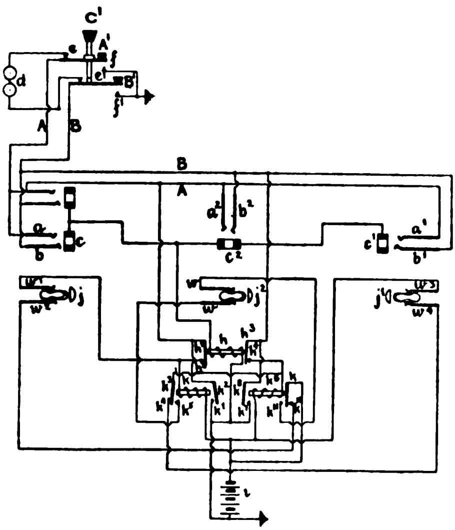


FIG. 17.

have another tongue, which rests normally against an outer contact, but when actuated by the armature when the relay is energised breaks from this point and makes contact with another. Normally the circuit of the A and B lamps are completed through these contacts. When, however, the relay L.R.[2] immediately associated with the A group of boards is energised the circuit of the B lamp C.L.[2] is cut; similarly, when the B relay L.R.[1] is energised the A lamp C.L.[1] circuit is cut and if, therefore, both relays be energised at the same time the circuits of both lamps will be cut. The circuit of the lamp C.L.[3] in connection with the No. 3, or C, group of boards is then established, the circuit then being from the earthed central battery through pilot relay, P.R.[3], through the tongue and inner contact of the line relay, L.R.[2], through I.D.B., through the C lamp to the inner contact and tongue of the line

relay, L.R.[1], through the right-hand outer contact and tongue of the cut-off relay, C.O.R., and the other tongue and under-contact of the line relay L.R.[2] to earthed side of battery.

Samples of suitable relays are on the table. With modern improvements the dread of double and triple contact relays has disappeared.

At the substation three push-buttons are fitted (Fig. 17), and, according to the number required, the subscriber presses the A[1], B[1], or C[1] key. When the A[1] or B[1] key is depressed the A or B calling lamp glows, as described for the two-division arrangement, and when the C[1] key is depressed both lines are earthed and both line relays are energised, the circuit of the A and B line lamps is cut and the lamp associated with the third, or C, group of boards glows. When an answering plug is inserted the cut-off relay is energised and the local retaining circuits are broken and the C lamp ceases to glow.

The foregoing arrangement can be used practically with any cord circuit. The following are a few examples. In the ring-through cord circuit (Fig. 2) the cord is bridged by a suitable differential retardation coil C, having its centre point connected through the coils of a relay D, to the earthed central battery, a lamp E being in parallel with this coil. The side of the relay coil farthest from the battery should be connected to the contact of the relay, the tongue connected through a spring and contact of the listening key L to earth, so arranged that the relay circuit may be broken in the listening position. When a connection is made and any one of the plungers at the substation is depressed momentarily the armature of the relay is attracted and a local circuit established which retains the armature, and therefore the clearing lamp glows until the operator brings the key to the listening position or withdraws the plug.

This arrangement may be used in conjunction with the ring-through, system, in which one subscriber rings the bell of the subscriber wanted or the operator may do the ringing. In the former case a generator is supplied with each instrument, in the latter case this is not necessary.

In the ring-through system with relay and lamp which was designed to replace the now practically obsolete call-wire system I preferably use a cord circuit without listening key as shown on Fig. 14.

The operator's telephone is normally in circuit through the back contacts of a triple relay in the third conductor of the calling cord. The operator is therefore ready to answer immediately she inserts the answering plug, but when the connection is completed by the insertion of the second plug her telephone is automatically cut out, as a local circuit is completed from earthed battery, through coil of triple relay, through sleeve of plug, bush of jack, over-test wire, through coil of cut-off relay to earth.

This combination, it is believed, will form the simplest manually operated switchboard known. The operating is as follows:—

(*a*) When the lamp glows operator inserts answering plug.
(*b*) Tests line wanted, and if free inserts plug into jack of line wanted.
(*c*) When clearing lamp glows she withdraws plugs.

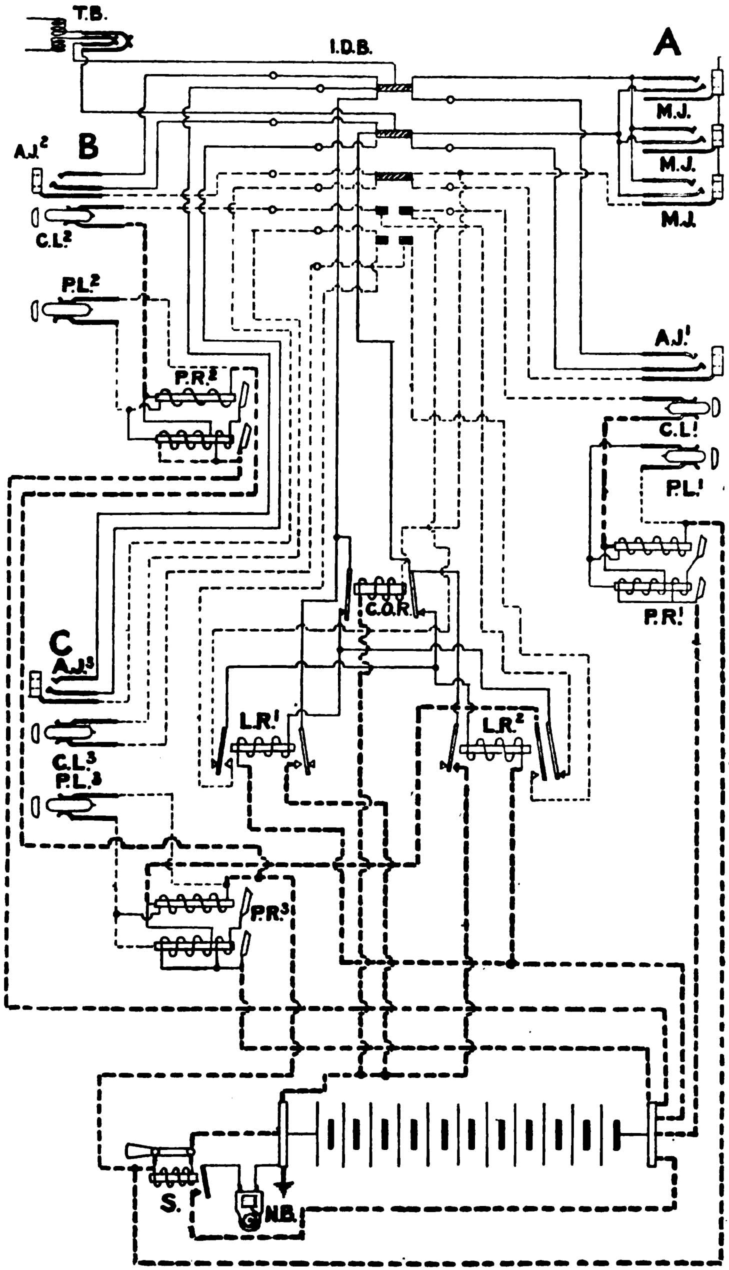

T.B.
I.D.B.
A
M.J.
M.J.
M.J.
A.J.2
B
C.L.2
P.L.2
P.R.2
A.J.1
C.L.1
P.L.1
P.R.1
C.O.R.
C
A.J.3
C.L.3
P.L.3
L.R.1
L.R.2
P.R.3
S.
N.B.

FIG. 18.

Such a system, up to the present, has only been proposed with central battery signalling, a primary battery at the subscriber's being used for speaking.

The divided board system will work also most efficiently with the Western Electric Company's common battery cord circuit when automatic clearing on two lamps and speaking from central battery are obtained. (Fig. 15.)

With the circuits of the Kellogg Switchboard and Supply Co., Fig. 7 it will also work excellently; in fact, this company have specially laid themselves out for building large exchanges on this system. Their circuits have only two wires in the multiple and two-way plugs, and they have, therefore, been able to reduce the size of their standard spring jacks to three-tenths of an inch face measurement instead of the $\frac{3}{8}$ in. as is usual, and I believe they are now manufacturing switchboards of 20,000 capacity per division.

I would propose forming one huge central exchange of from 30,000 to 60,000 lines in the heart of each great city, this exchange serving an area of about 14 square miles; this, of course, would vary with the density of the population, and the prospective number of renters. With an underground system, and cables containing from 250 to 300 pairs each, such an arrangement is perfectly feasible. Four main conduits should radiate from the central building, each containing from 50 to 80 ducts, these branching out, as required, up to a distance of from 2 to $2\frac{1}{2}$ miles from the exchange. Outside this area, say at $3\frac{1}{2}$ miles' distance from the central, subsidiary exchanges should be formed. When these exchanges are of considerable size they would have direct junction lines to the central, and incoming junction sections on each of the three multiples of the central exchange; where, however, the junction lines were few the operator would call the multiple required at the central by pressing the corresponding key in the same way as a subscriber.

The outgoing junctions for these subsidiary exchanges would only be multipled over one group of boards at the central, say the C group, so that subscribers would call, say, numbers 1 to 16,000 by depressing the A key, 16,001 to 32,000 by depressing the B key, and 32,001 to 45,000 and all subsidiary exchanges by depressing the C key. These numbers of lines can perfectly well be placed within the reach of the operators by using for the A and B multiples 6 feet 3 inch frames having 9 panels of strips of 20 spring jacks measuring $8\frac{1}{4}$ inches by $\frac{3}{8}$ inch. Eighteen blocks of 100 jacks give a height of about 2 feet $9\frac{3}{4}$ inches. The answering jacks and calling lamps and number pegs, in strips of 20, with space sufficient for 533 lines per operator (this being about equal to 177 lines on a simple multiple, as each operator only attends to one-third of the total number of subscribers' calls on a three-division system) would occupy a height of about $11\frac{1}{4}$ inches, so that the height of the upper row of spring jacks above the keyboard would be about 3 feet 9 inches.

The C line of boards could either be made to accommodate a slightly smaller number of subscribers' lines, so as to leave room for the outgoing junctions, or the section could be still further increased in length.

For a 45,000 line three-division exchange, reckoning that each operator can attend to an average of 150 lines per multiple board, or a total of 450 lines, the A and B groups would each consist of 107 multiple sections; while reckoning that each operator at the C group could attend to 100 lines only owing to the amount of junction work, 130 sections would be necessary.

Each group of switchboards (and possibly also separate intermediate and main distributing frames) should preferably be in a separate fireproof room in practically separate buildings, so that in case of fire the fireproof doors between could be closed and so confine the breakdown to one group.

The premises should, therefore, consist of one central building with flanking wings. In the basement of the central building one main distributing frame should be fitted, arranged radially in four sections of 12,000 or 15,000 in the shape of a Greek cross, the four conduits opening out at the ends. On the ground floor should be similarly arranged the intermediate distributing board and relay racks, the former having two or three distributing fields, as it may be necessary for equalising purposes to cross-connect the lines on one group of boards and not on the other. In the central building might be the C switch room, the A and B switch rooms being in the right and left wings respectively. Preferably the groups or divisions of the exchange should grow uniformly, as will be made clear by the following example. If it is desired to convert a 9,000-line ordinary exchange into a two-division exchange, and it is necessary to begin the second group with a capacity of 2,000 lines, then whilst it is only necessary to provide 2,000 extensions of answering jacks and lamps on the 9,000-line frame, for which there is plenty of room, the 9,000 lines require lamps and jack extensions on the sections built for 2,000, and each operator would have an abnormal number of lamps and jacks from the first line in front of her, and these would require to be redistributed when further extensions were made.

I think it must be granted, from what I have said that, from an operating point of view a great boon would be obtained by the introduction of the Divided Multiple Board System. Also that the made-up or speaking circuits would be much simpler.

As far as I can see the principal objection that can be urged against it is that the system depends for its efficient working upon the co-operation of the subscribers. We have been told that "men are mostly fools." Must this be taken literally? I think at any rate, not sufficiently fools to spoil a divided system by wilfully or carelessly calling on the wrong group or division of the exchange.

COMPARATIVE ESTIMATE OF EQUIPMENT NECESSARY FOR TWO 15,000-LINE EXCHANGES CONNECTED BY JUNCTIONS AND ONE 30,000-LINE TWO-DIVISION EXCHANGE.

Apparatus for two 15,000-line Exchanges.	Description of the Apparatus.	Apparatus for a 30,000-line Exchange.
30	Incoming junction sections (at 7½ %)	None
100	Subscribers' sections	66⅔
1,950,000	Multiple spring jacks	1,000,000
337,500 yds.	63 wire cable (30 yds. I.D.B.) ...	195,000
168,750	Outgoing junction jacks	None
40,500 yds.	33 wire cable	"
30,000	Answering jacks	60,000
30,000	Calling lamps	60,000
30,000	Double cut-off relays	30,000
30,000	Line relays	60,000
175,500 yds. (1,500 lengths at 117 yds.)	84 wire cable	198,000 (3,000 lengths × 66 yds.)
2,250	M.C. junctions × length X ...	None
2,250	Repeater coils for junctions ...	"
2,250	Condensers for junctions	"
2,250	Relays (12,000 ohm + 20 ohm) ...	"
2,250	Relays (local clearing)	"
2,250	Relays (on third conductors) ...	"
2,250	Clearing lamps	"
2,250	40-ohm resistance coils	"
2,250	30-ohm resistance coils	"
90	Call wires between Exchanges with equipment	"
2	Lines of tabs on I.D.B.	3
1	Cross connecting wire per line ...	2
	Twin switches on instruments ...	30,000
390	Operators	200
39	Supervisors	20
845 ft.	Length of switchboard ... ... (Practically the two-division equipment can be fitted in a building necessary for one of the 15,000-line Exchanges, and therefore there would be a great saving in cost or rent of buildings.)	433 ft. 4 in.
	Increased length of lines ... ... (If the 2,340 junctions and call-wires were each two miles long, this would be equal to an average increase in the length of each of the additional 15,000 lines of 550 yards.)	X × 15,000
	Mileage of wire saved in the two-division Exchange ... ... (This used outside would increase the average as above to about 880 yards.)	5,707
75	Value of service	100
2	Power Plant with maintenance ... (Great economy will be effected by using one large Power Plant instead of two smaller ones.)	1
2	Power Board Staff	1
2	Engineers-in-charge	1

TABLE OF CONTENTS.

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Patent No. 5,928, March 30, 1900. W. Aitken.
Patent No. 10,124, June 1, 1900. J. E. Kingsbury.
Patent No. 18,031, October 18, 1900. Milo G. Kellogg.

Mr. Laws Webb.

Mr. Herbert Laws Webb: I have read Mr. Aitken's paper with a great deal of interest. The telephoning of very large cities is a subject which, of course, telephone engineers look at as a daily increasing problem. I am quite sure that all telephone men must admire the ingenious manner in which Mr. Aitken has worked out the circuits of the divided multiple system to adapt them to common battery working. However, on the broad lines of the problem my opinion is that it is working in the wrong direction to advocate divided multiple exchanges. In the first place, such a system largely increases the line plant. It must necessarily greatly increase your average length of subscribers' line if you divide your city up into very large districts, and I think it will be found in all large telephone systems that the line plant represents by far the greater proportion of the cost of the whole plant. I think even where line costs are the cheapest the percentage of cost of the line plant is about 60 per cent. of the cost of the whole system, and to save in the exchange plant, which is the smaller item of cost, and increase in the line plant, seems to me to be working in the wrong direction as far as cost is concerned. I think in very large cities, where it is well known that the expense of building underground lines is much greater than in smaller places, that would bar out the divided multiple board altogether on the question of capital cost. The other point that seems to me to be very largely inadvisable with this system is that it puts back the operating of the service into the hands of the subscriber. With the common battery we have practically taken the operation of the service entirely out of the hands of the subscriber. The subscriber has the simplest action to perform; lifting the telephone off the support, which he must do in order to use it, automatically gives the calling signal, and in replacing the telephone, which I suppose 999 out of 1,000 do properly, he automatically gives the signal to disconnect. That gives us undoubtedly the cleanest, the quickest, and the simplest service that it is possible to give. In all systems where part of the operating is done by the subscriber there are numerous troubles due to the subscriber's lack of proper care in operating. If you put these two or three buttons on every instrument for the subscriber to press according

to whether he wants one number or another, in very many cases he will press the wrong button and get the wrong operator. Then you may expect something like this to happen: the subscriber gives the number that he wants, and the operator says, "You have pressed the wrong button." He says, "What?" Then the operator gets a little more impatient, and says rather shortly, "You-have-pressed-the-wrong-button!" And the subscriber says, "Hang your buttons! Why can't you give me my number?" In a great many cases that is bound to be what would happen, more or less. The language in some cases would be worse, and in other cases it would be better. Consider, for instance, one of Mr. Aitken's proposed world's capitals systems of 115,000 subscribers. You would have an average daily traffic there, at flat rates, of well over one million calls. All of those million calls would not come from expert subscribers. It is not always the man who signs the contract who uses the telephone; it is used by all sorts of people, from the office boy down—or up, according to which way you look at it—and it is used very largely by strangers. Every world's capital always has a large floating population, and if you have 115,000 telephone stations you would have a large number of public stations, so that a large proportion of your daily traffic would be from people who are not expert in using that particular system. Therefore a pretty fair percentage of your million calls a day would be calls that would be sent in wrongly. That would give trouble; that would need extra attention, unprofitable work on the part of the operators and the supervisors and the rest of the exchange staff. I do not think that you can plan out any telephone system nowadays—we have learnt something of late years of the telephone-using public—without keeping a very careful eye on the public and on what it does with the telephone at the public end of the system. Mr. Laws Webb.

There are one or two points that occur to me in Mr. Aitken's estimates of operating values. I noted somewhere that he reckons a junction call as being the equivalent in time of two local calls. That seems to me quite excessive—that it should take twice as long to operate a junction call as a local call completed at the same switchboard. The experience in New York, which for the past eighteen months or so has had uniform common battery working, is that the difference in time between completing a local call and a junction call is nothing like so much as that. The very careful tests made of a large number of connections, and tabulated with great care, show that the actual time is 23 seconds odd for a local call and 30 seconds for a junction call. There is almost exactly 7 seconds difference between them. That is, a junction call does not take longer than $\frac{1}{3}$ more than the local call. That, of course, gets rid of a good deal of the argument in favour of the divided multiple board. If your junction call does not take longer than 30 seconds to operate, there is not a very strong argument against junction working. As a matter of fact, having the relay system in use uniformly, so that all the exchanges are worked on the same system, and all the operators are trained to do the same class of work exactly, there is practically very little difference between the completion of a local call and a junction call.

Mr. Laws Webb. The question of handling very large numbers of subscribers has been solved in New York a good deal in this way, that a large number of what you might call satellite exchanges have sprung up owing to the use by subscribers of what we call private branch exchanges, the private branch exchange simply consisting of a miniature exchange—it often grows to be a pretty large one—on the premises of the subscriber. That class of service was at first introduced to give a good service to very busy subscribers. We found that a great many subscribers were over-using their lines, and were blocking their lines entirely to the inward calls. We persuaded those very busy firms to take a branch exchange outfit consisting of a switchboard connected by a number of trunks to the nearest exchange, and from the switchboard were extended instruments to the different departments and offices of the people who had to use the service. A trained operator was put at the switchboard, and the whole service of that subscriber was handled through that private branch switchboard. At first it was pretty difficult to get business concerns to take up that class of service: it cost more, and they did not see why they should not use a telephone in the old way, that is, working one flat rate line so that it was used almost exclusively for outward calls and gave the inward traffic no chance at all. However, that private exchange system gave so much improved a service, and handled the traffic of a busy subscriber so effectively, that it very soon became popular, and now instead of having to push it by means of canvassing, and so on, it has become the accepted thing, and there are actually in New York in private employ, operating branch exchange switchboards, about twice as many trained operators as there are in the main telephone exchanges themselves. There are, I should think, at a rough guess—I have not got the exact figures in my mind—approximately 30,000 stations out of 100,000 stations in New York that are operated on private branch exchanges. That method of working the telephone service undoubtedly largely helps us to solve the question of dealing with very large numbers of subscribers. Where you have big establishments, such as large hotels and large apartment houses, it gives an admirable service, and it of course largely saves in the number of lines required to serve a given number of telephone users. It is the practice now in New York to build no large apartment house or large hotel without putting in a private branch exchange with a telephone in every apartment, and I think, in fact, the New York Telephone Company has contracts for private branch exchanges to be equipped in hotels that are not even yet built, so thoroughly is the use of the telephone recognised in New York.

Mr. Gill. Mr. FRANK GILL: Mr. Aitken's paper is somewhat unusual in that, instead of propounding a definite problem of known factors, he gives a somewhat speculative paper. But I do not think it is any less important on that account, because it deals with a very large and difficult subject, and even on the "cheap and nasty" plan his 115,000 subscribers involves figures running into some millions. I should like to congratulate Mr. Aitken on the ability he has shown in handling his subject. For reasons which are fairly obvious I prefer not to express any very strong opinion one way or the other, but I desire to point out one or

two things which should be borne in mind by telephone engineers who contemplate putting in a divided board. In the first place I understand there are only two divided boards in existence, one in St. Louis and one in Cleveland, each for 20,000 lines. One most important factor which comes in is time. Every telephone subscriber wants to get through almost before he makes his request, and I doubt very much whether there is anything in the commercial world or in the scientific world which is cut quite so fine as ordinary telephone operating. The first query which comes is this, I rather want to apologise to the Institution for trying to introduce a new factor; we have such a lot of factors that one hesitates to bring in another one, namely, the time-factor. The time-factor of a subscriber's line is, we know, roughly about 2·28 per cent.; the time-factor of a junction line—or, as they call it in New York, a trunk line—is about 23·5 per cent. That immediately raises the very important fact that, if you are going to extend copper, you extend copper which will be used in one ratio or in the other. In Mr. Aitken's Fig. 1, I have assumed, taking out figures as far as I could without knowing the conditions of the locality in which the exchange was to be planted, that there would be 115,000 lines, which would equal about 70,000 miles of metallic circuit; there would be, in addition, about 60,000 miles of metallic circuit for junctions. In Fig. 9, I make out there would be something like 172,000 miles of metallic circuit for subscribers' lines, and about 14,000 miles for junctions, a very considerable reduction. The difference, therefore, is 56,000 miles of metallic circuit against Fig. 9, which is approximately about 1,000 tons of copper. Perhaps telephone men will follow the point a little easier if I say 183 miles of 306 pair cable. It is a serious item, which you must consider, and see whether what you get is worth it. On the intermediate distributing board there would be three divisions, two of them extra. There would be probably something like 123 tons more of copper on those two. The jumpers for the two divisions would be extra. There would be also a whole lot of smaller details. The intermediate boards would be each full size, and the main frame would be larger. The line lamps, the line relays, fitted with a back contact in a doubtful situation, would be more—I am sorry Mr. Swinburne has gone, because I wanted to tell him that we no longer wind electromagnets with german-silver wire, if indeed it was ever done—there would be also the keys on the instruments. Against these items—I have not noted them because Mr. Aitken has covered them very fully—there would undoubtedly be a large number of savings. Mr. Webb has rather anticipated me in regard to the question of the ratio of junction calls. In the paper (page 814) a problem is worked out which is based on the ration of 1 : 2. I make out that if one takes the ratio as 1 : 1·3, instead of requiring 66 $\frac{2}{3}$ sections one will only require 51 $\frac{2}{3}$ sections. The distribution on a divided board is much more difficult, because you have to distribute each section of the intermediate board separately. In calculating the average numerical chances of junction working, in Fig. 1 we have 97 per cent.—that is, the chances of the call being an outgoing call—and in Fig. 9, 89 per cent.; but, of course, you have to consider the direction of the traffic. Mr. Gill.

Mr. Gill.

I would conclude by one suggestion, that if, as I have endeavoured to show, the length of the subscribers' line in a divided board system is a serious item, and one which requires to be considered carefully, then the same item also requires grave consideration in any attempt made to bring two exchanges together in one building, where one gets all the junction work and none of the advantages of the divided board.

Mr. Harrison.

Mr. H. H. HARRISON: I have been very interested in the paper which has been read, as the question of the adoption of divided multiple boards interested me some five or six years ago, before Mr. Kellogg brought out his important patent. Mr. Aitken seems to have assumed that we all know the necessity for divided boards. Briefly, it is, of course, that, as the number of subscribers goes up, the multiple connections, or panel area, required to enable the operator to communicate with any subscriber become so great that it is no

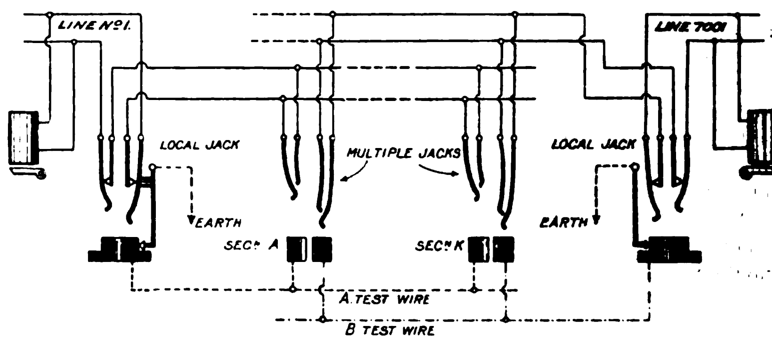


FIG. A.

longer possible for one operator to complete the connection. Hence this gave rise over the other side to what was called, I believe, the "express" system. That consisted of two boards—one in which the calls were received, and the other board, or B board, as it was called, in which the connection required was effected. This, in turn, necessitated call-wires between the boards and two operators for every connection made. The divided board system, as described, is very ingeniously worked out, but I think it might be found rather difficult in practice. For instance, it is pretty certain that the number of divisions would have to be limited to four, because with an ordinary metallic loop no simple system of selective signalling is possible in more than four ways; and while I do not think it is too much to ask a subscriber to select one of four buttons, any more than it is asking too much of him to look up the number of the required subscriber in his telephone directory, he might reply, if you ask him to make combinations with four buttons—the telephone subscriber is rather an impolite person—that he was not having any; so it is pretty certain, therefore, that that limits the number of divisions to four. I would point out that the excellence of Mr. Aitken's divided board service might be such that in course of time he would have each one of his four boards

beginning to grow unwieldy, as the early multiple boards did, and then he would be in the same difficulty as the early telephone people were. I therefore want to describe a system called the Duplex Multiple Board, which was invented over the other side, I believe, one exchange of which was worked on the system. As it requires a diagram to adequately describe it, I will ask your permission to communicate the rest of my remarks. Mr. Harrison.

(*Communicated.*) In the duplex multiple system the subscribers are divided into two groups, A and B. Each line terminates in a local jack in the usual manner. The multiple jacks are of special construction. They consist, as shown in the diagram, Fig. A, of two pairs of line springs to which the A and B lines are connected respectively, and the bushes are split to form the necessary testing circuits.

It is claimed for this board that its capacity can be increased to double that of the ordinary type, the multiple area remaining the same. It has, however, two serious disadvantages. Three plugs are required, an ordinary answering plug and an A and a B plug; further, care is required in testing for the engaged signal to see that the right half of the bush is touched.

It is, however, an interesting attempt to reduce the number of the junction lines by increasing the capacity of the central exchange without, at the same time, requiring a system of selective signalling.

Mr. J. E. KINGSBURY: I should rather have preferred, sir, that somebody having more confidence in Mr. Aitken's system than I have should have spoken at this stage, in order that he might have had some of the support which I feel he deserves, if only for bringing such a paper before us. We have lacked telephone papers, and are therefore very much indebted to him for the one which he has read. I think, however, there is some danger of our taking his paper too seriously. I am not at all sure that Mr. Aitken has not brought this paper before us as something for discussion, rather than for us to assume that he is prepared to take the responsibility of the adoption of the system he proposes in one of the world's capitals. I believe the system has not yet been put into operation. It is something, therefore, of an experiment; and one of the world's capitals is the last place in the world where any responsible telephone engineer would think of trying experiments. For that reason I think we need not, as I say, consider it altogether too seriously. But we must recognise the fact that in the development of the telephone growth which must come we shall need all the invention that we can get, and it is even possible we may have to call upon the public to do what Mr. Aitken is perfectly ready to allow them to do. But before we do that I feel that we must exhaust many other sources of invention that we have not yet touched. Let us consider what it is that Mr. Aitken proposes. He proposes that we shall have a series of switchboards, on each of which a portion of the jacks shall be multipled. We can get a better mental conception of the arrangement if we assume a series of boards painted different colours; we will call them red, white, and blue. Upon each of them is a signal, which may be operated at the will of the subscriber by pressing a selected button; and under such circumstances we should Mr. Kingsbury.

Mr. Kingsbury.

naturally make the buttons a series of similar colours. Press a red button and you drop a signal on the red board, and so on. That is what is called "selective signalling." We had such a system in connection with the "ring through" system, adopted by Mr. Poole in the early days at Manchester. There was one kind of indicator which would drop by pressing a white button, and another kind of indicator, a clearing indicator, which would drop by pressing a black button. In those days there was only one line, but both poles of the battery were utilised, one by the white button and the other by the black. On the introduction of the magneto there was a somewhat similar use of a single line, by sending an alternating current on one occasion and a commutated current on another. That gave us an opportunity by magneto working of selecting either one of the two signals. The introduction of metallic circuit working and central battery working gave us an opportunity of four choices, and really there is very little reason why, since a four party line is an easy thing to operate, a four area system should not be utilised, working on the common battery. Of course it involves a large quantity of abstruse diagrams and a large amount of technical ability to work them out, but in essence that is what it amounts to. Mr. Aitken has gone into the question of comparative costs. I do not propose to follow that in any detail; it has already been done by other speakers. But I would like to emphasise Mr. Webb's remarks in regard to the operation of the system by the public. I anticipate that Mr. Aitken will consider that his reliability on the public is not so misplaced as some of us think. My impression is that a telephone engineer regards his subscribers individually as not only men of very great sense and ability, but I am not at all sure whether he does not consider them all Senior Wranglers. The police regard the individuals of society as most law-abiding people, but they have a method of dealing with crowds which leaves the individual, and the law-abiding character of the individual, out of account. The telephone engineer, in dealing with the public, has to adopt a similar distinction between individuals and telephone subscribers. It is perfectly useless for us to depend upon a member of the public—perhaps an impatient man of business, whose telephone call may mean thousands of pounds—to press the right button or do the right thing at all unless it is absolutely the most simple thing. For that reason alone I think Mr. Aitken's method of a divided board cannot be expected to be put into operation until, as I say, other methods have been exhausted. Why does Mr. Aitken suggest the divided board? Mr. Kellogg suggested it probably ten years ago. He suggested it when the limitation of the multiple board was about 6,000; to-day it is 20,000, to-morrow it will be 30,000; and I see no reason to assume that we should regard that number as in any way within reach of the limit. All we can say at present is that the multiple board has grown in its capacity with the requirements of the business. I see no reason at all why we should assume that its progress has stopped, and I think we may take it that in that direction inventive ingenuity would be well displayed.

Mr. Gavey.

Mr. J. GAVEY: Sir, I think Mr. Aitken has placed the Institution

under a debt of gratitude for having brought this very important matter before it to-night. Many of the speakers who have preceded me have made remarks which in some cases have anticipated my own. In reference to certain criticisms I should like, however, to say that we have not reached anything like finality, and that we ought to, and we do, welcome every attempt that is made, or every suggestion that is brought before us, with a view of improving the telephone service of the country. The problem which is ever present to the mind of the telephone engineer is simply this—to place the subscribers in communication in the shortest possible interval of time, with a due regard to a reasonable capital expenditure, and by the employment of the fewest possible number of operators. This problem has been ever before them, but as new devices have been introduced which appeared to simplify the problem the difficulties have increased, owing to the growth of the population and the growth of telephone subscribers. As the last speaker said, it is only a few years ago when the multiple board was supposed to meet the requirements of a given locality with a capacity of 6,000. Now a multiple board of 15,000 is actually in existence. A 20,000 board is designed, and that is still far from meeting the requirements of the public; and if anything in the nature of Mr. Aitken's proposal—which certainly is an honest endeavour to meet the difficulty—can be adopted, then I say he is conferring a benefit on the community in bringing the subject forward. The divided multiple boards that have been used in America can hardly be said to bear very seriously on the problem, because they do not provide automatic signalling—at least those that I saw did not. They are all the old type, involving ringing up and ringing off, and whatever may be said for or against them there is very little in common between them and those proposed by Mr. Aitken. Mr. Aitken's statistics are not universally applicable; some of them have been referred to by other speakers. With reference to others, I should like to point out one or two matters, not in a carping spirit, but merely with a view of preventing any misunderstanding. The author has made certain definite statements as to the number of subscribers per operator, the work carried by junctions, the time in getting through, etc., etc. I should like to point out that you cannot determine these factors directly without first of all postulating the number of talks per subscriber and the type of apparatus that you are using. In the first place, with reference to the apparatus, I do not think you can make any definite comparison between the old type of ringing on and ringing off and the modern type of automatic signalling. I have a very firm conviction that the introduction of automatic signalling, in which you merely remove the telephone to call and place it back to clear, in which the signalling on the junctions is wholly automatic, in which the talking is reduced to a minimum, the operator simply being called upon to ask for the number—and by the signalling she sees perfectly well what is going on without intervention—I cannot help thinking that with a system of that sort, a system which I think before many years we shall see universally employed, the capacity of an operator and the carrying power of the lines will be absolutely doubled. I

Mr. Gavey.

Mr. Gavey. must confess that I have some sympathy with certain of the speakers on the question of reducing the work of the public to a minimum. At present, with the automatic system, that is absolutely minimised. Tell it not in Gath, but I also am a telephone user, as well as being connected with the engineering branch of the Post Office telephones. I happen to have on my table a little switch with three keys. I am frequently called to the telephone when immersed in business, immersed in thought. I think at such a time that the telephone is a nuisance, but I have to answer it. I answer it as quickly as possible: I put it down and go on with my work, and presently somebody rushes in hurriedly and replaces the key, which I myself have forgotten to do. I hope I am not an unintelligent user of the telephone, but I mention that as one of the difficulties you have to contend with, apart altogether from want of ability or want of care. When a very busy man who is immersed in business, whose mind is full of very important matters, is interrupted he just does what he has to do, and no more, forgetting the little details that are involved in the special work of clearing off.

Mr. Aitken. Mr. W. AITKEN, in reply, said: Mr. Webb made considerable reference to the cost of the outside plant, but it is to be noted that in my schedule of quantities I have shown how an increase of 550 yards on each of the second 15,000 lines is obtained by the reduction in the number of junction lines. It is also to be remembered that the great mass of wires centralised on one great exchange will be cheaper per mile owing to larger capacity cables being used and the decreased cost of labour in laying. Mr. Dommerque, of the Kellogg Switchboard and Supply Company of Chicago, takes a great interest in this subject, and I would take the liberty of quoting some information given in correspondence I have had with him. In a report made by him some years ago, which is still valid as regards arguments but out of date as regards prices of materials, he says: "As the cost of the installation of the wire plant is not the item that is involved in the cost of telephone service, but the annual expense, the interest and depreciation, maintenance and taxes on the wire plant is the factor that must be taken into consideration when comparing the preference of one system over the other." From this he goes on to compare the two systems, allowing 0·35 miles of wires per subscriber for the junction system, and 2·6 wire miles on the divided system when dealing with one 10,000 line exchange against four 2,500 line ones connected by junctions, and yet shows a result in favour of the divided system. He concludes as follows: "It may be of interest to note some points in which the single-office system excels the multiple system outside of the monetary question. Necessarily the condensation of all apparatus into one unit allows of the best supervision and regulation of the system."

"More than anything else weighs the circumstance that each call in the one-office system is handled by one operator only, which not only allows of the highest speed in obtaining connection but also ensures less mistakes than when calls are handled by two operators as it is the case with the 60 per cent. or more calls that are trunked between the four or more offices of a multiple-office system. Even with the best trunking facilities it happens that in the multiple-office system during

the busiest hours just when the trunks are most useful the service breaks down." Mr. Aitken.

"Trunking requires more office cable and more contacts in the talking circuit, and thereby deteriorates the transmission of speech. The efficiency of apparatus like ringing machines, storage batteries and their charging machines, is greater with one-office system, because larger units are always more efficient and easier to maintain than smaller units, certainly when the latter are scattered over several places.''

Mr. Dommerque in his letter adds: "I wish, however, to state that with the introduction of $\frac{3}{16}$-inch and even $\frac{1}{4}$-inch jacks, large switch-boards can be built without going to division-systems. In fact, we would be able to build single division-boards for 25,000 subscribers. This, of course, will also increase the range of division exchanges, because, with these small jacks, we will be able to build division boards up to 50,000 lines, using only two divisions, and correspondingly greater, by using more than two divisions. The whole matter will sum up in the advisability of having only one exchange in a city, against several exchanges."

With reference to the other points raised by Mr. Webb, particularly that regarding the operating by the subscriber and which nearly all succeeding speakers have also remarked on, I think too much is being made of this, and that Mr. Webb is prepared to pay too much for uniformity. Get a subscriber to understand that by performing a certain act he will receive quicker attention with fewer possible mistakes, and I am sure he will do it. He wants a quick and reliable service, and is prepared to do anything reasonable to obtain it. Automatic clearing is essential on such a system as I advocate, but automatic calling is not essential on any system, in fact it may be looked on as a doubtful facility. The absent-minded man may unconsciously allow the lever of his desk telephone to rise and indicate a call, or the charwoman or servant when cleaning remove the receiver to more conveniently perform her duties, thereby giving the operator unnecessary work and trouble.

It is to be borne in mind also that business men use press buttons—and more of them, and often code-riming on each—in connection with bells to call clerks, and when a mistake is made the man usually recognises that he has wasted his own time and that of his clerk unnecessarily and is more likely to be apologetic than use Mr. Webb's phrases.

The buttons might be coloured as mentioned by Mr. Kingsbury, red, white, and blue, and all numbers in the book would be preceded by one or other of these words, so that there would be no excuse for mistakes. Why does a subscriber on the present system not ask for Avenue when he wants Gerrard? One is almost as likely a thing to do as the other.

Mr. Webb thinks my values of calls too high—probably they are if you consider only calls from one exchange to another, but what about those that pass through one or two intermediate exchanges, which take much longer? The average is not very far out. I should like further particulars of Mr. Webb's figures—figures have a bad reputa-

Mr. Aitken. tion. The following will give an idea of the work required for the two calls :—

LOCAL.

(1) Inserts plug in jack over lamp glowing.
(2) Pulls over listening-key and takes requirements from subscriber.
(3) Tests line wanted, and if free inserts plug.
(4) Puts key in through position.
(5) When cleaning lamps glow withdraws two plugs.

JUNCTION.

(1) Inserts plug in jack over lamp glowing.
(2) Pulls over listening-keys and takes requirement from subcriber.
(3) Presses call-key and repeats number wanted to distant operator (may have to wait her turn or repeat number more than once).
(4) Junction operator allots line, tests line wanted, and if free inserts plug in jack.
(5) Presses ringing-key.
(6) First operator inserts plug in junction jack.
(7) Pulls key to "through."
(8) When cleaning lamps glow withdraws two plugs.
(9) Junction operator withdraws plug.

I find it difficult to understand Mr. Webb's reference to private branch exchanges relieving the great centrals to any appreciable extent. Very few firms in this country at least would care to pay for an exchange line when a local private line would serve the same purpose. There is certainly room for developing the private branch exchange business.

With reference to Mr. Gill's remarks, for obvious reasons I could not very well deal with a definite problem; I should certainly have preferred doing so, and have no doubt I could have shown even better results. To the telephone engineer who would consider the points put forward by Mr. Gill, I would say, Do not overlook the other points put forward in favour of the divided system. As before mentioned, the maintenance costs require careful attention and will be found to well outweigh the capital costs. Mr. Gill's alarming figures of excess weight of copper in my system are based on a hypothetical case, and I believe have no sure foundation—at least are not sufficient to outweigh the other advantages.

With regard to the percentage of junction calls, I think most subscribers would be content to wait twice as long for a few calls to their houses in the suburbs if they were assured of getting the great majority of their business calls in the shortest possible time. If Mr. Gill deducted the small exchanges from his figures the results would be very different.

Mr. Harrison's alternative system, judging by the meagre descrip-

tion given, is in my opinion practically unworkable. I believe he means to put two subscriber's lines on one springjack by using springs of different lengths and a split bush or test ring. On a 10,000 line exchange an operator could not test with certainty. When a call was received for the B subscriber when a connection had already been made by the same operator to the A subscriber, how would it be done? Would not the jack need to be enlarged to get in the six connections and the necessary cable? Mr. Aitken.

I have some difficulty in understanding Mr. Kingsbury's opening remarks. I have not read my paper to provoke discussion, but to describe a system I believe capable of providing an efficient telephone system for the world's capitals. The system is beyond the experimental stage in at least the two divisions—in that there is nothing untried, and only in one of the great cities can the experiment (if experiment it can be called) of introducing it be efficiently tried—and when some engineer or corporation with sufficient courage does adopt it I have no fear of the result.

Mr. Kingsbury refers to Mr. Poole's system used at Manchester some years ago. The idea was excellent—the push-button arrangement had, I understand, nothing to do with the partial non-success of the system, but the weakness lay in the polarised ring-off indicator.

Mr. Kingsbury's four-area system is altogether too vague to allow of its being considered here.

When writing my paper I overlooked a patent taken out by Mr. Kingsbury's Company on June 1, 1900, for divided boards on a somewhat similar system to mine, but instead of using two push-buttons, two instruments were to be connected to the line at the subscriber's office. This is open to all the objections of the push-button.

I have to thank Mr. Gavey for his kindly remarks. I agree with him as to the object to be aimed at in designing a telephone system. There is no doubt the ideal system should have all subscribers in the same telephone area in one exchange. In the world's capitals this, with our present knowledge, is not possible, but the nearest approach to it should certainly be made. To the various features necessary for quick and reliable operating mentioned by Mr. Gavey I would add the reduction to the minimum of junction working with complicated circuits and the necessity for the repeating of numbers by operations.

The PRESIDENT announced that the scrutineers reported the following candidates to have been duly elected:—

Members.

Harry Collings Bishop.	Edmund Munroe Sawtelle.

Associate Members.

John Arnot Anderson.	Edward Peter Grimsdick.
Albert Arthur Blackburn.	Harold Aislabie Howie.
Charles William Dawson.	William Arthur Molyneux.
John William Dawson.	Sidney Cuthbert Sheppard.
Axel Carl Ludwig Ekström.	Arthur Denby Smith.
Rudolph Goldschmidt.	James Herbert Targett.

Associates.

Leopold Charles Benton.
George Henry Broom.
William P. Dunne.
Arthur Herbert Flemming.
Algernon Coste Gilling.
Percy James Haler, B.Sc.
William H. W. James.
Harold Morton Middleton.
William Carmichael Peebles.
Alexander Russell Walker.

Students.

Algernon Edward Berriman.
Geo. Bradwell.
Ernest Phillip Elwin.
Herbert Geo. Jenkins.
Alfred Montgomery.
Stanley Robert Mullard.
Patrick F. Myers.
James Parkinson.
Alfred William Scrooby.
Arthur Douglas Taberner.
John Dodsworth Walker.
Arthur Ward.

GLASGOW LOCAL SECTION.

DISCUSSION* ON ELECTRIC WIRING UP TO DATE.

(*At Meeting held January 13th*, 1903.)

At a discussion on the above question which was opened by Mr. Chamen, attention was drawn to the number of outbreaks of fire which had occurred owing to bad wiring, which were attributed to the use of metal sheathed tubing with slip joints.

The opinion was expressed by Mr. Chamen and subsequent speakers, that this class of protection for wiring had not answered anticipations, and in fact it was doubtful whether it was as safe as wood casing.

Where iron tubing was used it was proposed that it should be made with screwed joints throughout and earthed.

* For a fuller account, see *The Electrical Review*, vol. lii., p. 329; *The Electrician*, vol. l., p. 1071.

NEWCASTLE LOCAL SECTION.

METHODS OF SUPPORTING AND PROTECTING INSIDE CONDUCTORS.

By O. L. FALCONAR, Associate Member.

(*Paper read at Meeting of Section, January 19, 1903.*)

Introductory.—In order to meet with the exigencies of the gradually increasing pressure of supply, and also to cope with the demand for more reliable and less expensive methods than those at present used, it is imperative for electrical engineers constantly to recur to a subject which has ultimately a most important bearing on the success of any electrical undertaking. In view of the general tendency towards standardisation in electrical apparatus which has been a prominent feature of the last decade, it is remarkable that "methods of supporting and protecting conductors" should remain in such an undecided state. Possibly this may be in some measure owing to the small amount of attention the general body of electrical engineers have given this subject, and to their confining their efforts more towards reducing the cost of production and distribution of electricity. That an improvement in the present methods is necessary is clearly shown by the excessive amount of labour required to carry them out; moreover, the cost of wiring appears to be increasing rather than diminishing, and this, in the face of recent vast improvements in gas-lighting, threatens, unless remedied, seriously to curtail the advancement of the use of electricity. As far as the author is aware, previous papers bearing on this subject have chiefly been confined to the discussion of some particular system advocated by or associated with the writers; hence the subject has not perhaps been considered in as broad a light as from the standpoint of a person who has in most instances to decide what method he will adopt, and is also held responsible, both morally and pecuniarily, for the good working of the undertaking. The author hopes on this occasion to consider as many as possible of the present systems in use, with the object of deciding which is the most efficient and economical method to be used for the various conditions required, and in order that this may be done he trusts that any member who may be familiar with systems not treated on in this paper will at the close take part in the discussion. As the conditions under which the conductors will be required to work ought to determine which system is requisite, it should be possible to divide them into various groups and to standardise to as large an extent as possible the method to be adopted for each case. The author has, therefore, endeavoured broadly to classify the conditions usually met with under the following headings:—

(A) *Exposed Positions.*—This may be considered to apply to the

wiring of very rough places—for instance, certain parts of shipyards, boiler shops, forges, collieries, etc., where damage to the conductors from mechanical injury, dampness, corrosive salts, gases, or other causes have to be provided against.

(B) *Ordinary Positions.*—Or places where damage from outward mechanical injury to any great extent is not to be apprehended, but protection against general dampness, vapours, corrosive salts in plaster, etc., must be allowed for. Instances of this class occur in all new buildings, mills, warehouses, and workshops.

(C) *Unexposed Positions.*—Or places where no deleterious effects other than the actions of the atmosphere, and general deterioration owing to ordinary wear and tear are to be encountered. Such conditions are met with in certain offices, shops, dry goods manufactories, etc.

The author does not wish it to be supposed that he considers the above classes should be made to embrace the whole of the conditions met with in practice, but in order to avoid the introduction of a subject which in the limited time at his disposal would be impossible to discuss fully, he has taken them as a basis on which to work.

CLASS A.—EXPOSED POSITIONS.

The requirements, then, in regard to the methods of supporting and protecting conductors for Class A may be briefly stated as follows:—The conductors must be rigidly supported throughout their entire length and protected by a substance which will withstand continual rough usage; they should, moreover, be protected from moisture and be capable of being added to or withdrawn without undue inconvenience. It is obvious that such substances as wood casing, insulating cleats, or any form of split tubing would be unsuitable for this class, and one of the commonest methods is to draw the wires into "iron gas-barrel."

IRON GAS-BARREL.

This, no doubt, has been, and is, in many instances, used with success, but there are many objections to this system. Lack of flexibility, interior roughness, extreme difficulty in preventing damage to wires in drawing in, and rapid deterioration of cables owing to internal moisture, are some of the principal ones. As the question of cost of each system will be considered later, this may at the present moment be ignored.

The difficulties which arise, especially where tubing of large diameter has to be used, in getting round irregular-shaped bodies with any pretence of neatness, will be appreciated by any one who has had experience in the wiring of motors used for driving large power machines in this class of conditions. Standard bends, elbows, and tees can in many instances be used, but where special bends are required for these purposes they waste an enormous amount of time and patience.

Interior Roughness.

The ordinary class of gas- or steam-tubing is, moreover, unsuitable for use as a protection to any but armoured cables owing to the interior roughness which invariably exists. This cuts through the covering of the cables when they are drawn through, and in time causes an endless amount of trouble. Tubing should only be used after having an iron rod of nearly the same diameter as the inside of the pipe driven through, and the ends should also be rimered to remove any sharp edges after this is done. It is important that insulating bushes of hardwood or other suitable substance should be fitted at the point of entry or exit of cables from any kind of metallic piping, and the author has records of numerous breakdowns of wiring owing to neglect in attending to this very simple precaution.

Screwing.

The screwing of this class of tubing, besides taking a large amount of time, is another source of danger to cables. The oil used for lubricating the die, unless carefully wiped off the tube, is very apt to get on to the cables, and plays havoc with any type of rubber coverings. The sharp edges left on the ends of the tubes after screwing are also likely to be overlooked and to puncture the insulation of cables. Though it may be thought these objections arise only where careless workmen are employed, yet they must always be guarded against, and with the class of workmen usually procurable extreme care is more than can be expected. Packing cables owing to the use of too small diameter of tubing is a great cause of damage. The author has found that tubing of less than ¾ in. inside diameter is little use in the case of a draw-in system where looping is substituted for jointing.

Jointing.

In jointing this class of tubing a watertight joint is not obtained so easily as is apparently supposed by many—viz., by running a few threads into a coupling without any form of packing. In moist places, no doubt, rust will in time help to fill up any crevice ; but where cables are led amongst machinery and in places where oil is likely to be scattered about, great care has to be exercised to avoid this finding its way through loose couplings. If red lead is used, it should be kept well off the end of the tube to which the coupling is screwed. Tarred spun yarn or asbestos twine appears to be suitable for making water-tight joints, but the author is not aware if they would resist oil. Possibly lead wire would be suitable for this purpose.

Internal Moisture.

The deterioration of cables through internal moisture produced by condensation is a defect common to all metallic tubing methods, and often causes serious faults to develop after the installation has

been working for some months. Whilst much of the moisture attributed to this cause finds its way from the outside through imperfect joints, in numerous instances which come under the author's notice this has undoubtedly been the cause of trouble. In long vertical runs, terminating at a switch or fitting, water often collects, and develops an earth or short-circuit. In horizontal runs it collects at bends or dips in the pipes, and the cables often break down at these points. There are three methods of overcoming this: (1) drainage holes or traps may be adopted, and the pipe given a slight fall to these positions; (2) the wires may be lead-covered or enclosed in some other suitable watertight covering; or (3) the tubing may be coated with a non-conducting substance such as paper, which is said to prevent the formation of moisture by condensation, this tubing being generally of welded steel of thinner gauge than ordinary gas-barrel. (*Note.*—The author has not heard of ordinary gas-barrel being coated with an insulating substance, but possibly this may be procurable.) The author believes the second method is to be preferred, as it is impossible to prevent moisture collecting in some parts of the tubing, in spite of drainage boxes or vents; and the third method, besides providing a porous substance which may, if water finds its way into the tube, remain damp for a longer period than an unprotected pipe, destroys one of the greatest advantages of iron pipe work—viz., the prevention of unnoticed leakage by immediate dead earthing, and consequent warning by the blowing of the fuse protecting that circuit.

Welded Steel Tubing.

Heavy-gauge, uninsulated, welded steel tubing of smooth interior can be obtained at a slightly higher cost than ordinary gas-barrel, and this overcomes the difficulties due to roughness. Other disadvantages arise, however. The thickness of the tubing is hardly enough to allow of a "Whitworth" full standard thread being cut, so the makers supply special dies cutting a much finer non-standard thread, which is a great inconvenience to users, especially as each maker recommends a different type of thread which he has found, after careful experiment, to be exactly suitable for the purpose. This seems like retrogression, and reminds one of the old days, when each engine builder manufactured his bolts and nuts with a special thread, so that future repairs would have to come his way. It seems unfortunate, also, that more uniformity does not exist in regard to the diameter of this class of tubing. Some makers apparently take the inside measurements, others the outside; some take the diameter in millimetres, others in fractions of an inch; whilst some disregard both, and arrange their tubing alphabetically, such as A size, B size, or C size. It is unnecessary to enumerate the benefits which would result if uniform dimensions were adopted by every maker, but possibly the makers themselves realise that any form of heavy screwed piping at its best is a superfluous and expensive method to adopt, and expect it to be superseded sooner or later by some simpler and more easily fixed system. One method which suggests itself to the author as a substi-

tute for iron piping in this class is the use of "armoured cables." In the author's opinion the protective substance should form part of the cable itself, and if this were of sufficient strength, the cables might be clipped on to the surroundings in the same manner as in an ordinary gas installation. There is, of course, nothing new in this proposal. The advocates of concentric wiring have endeavoured to introduce a system similar to this for years, but judging from the small amount of this class of work done at present (inside buildings), it is apparently not desirable to alter the present system of double wiring. There is no reason, however, why two armoured conductors should not be run in buildings of this class in the same manner as is done in most ship installations. In ship wiring this method has been used for some time with considerable success in positions in this class, and also in classes B and C.

CLASS B.—ORDINARY POSITIONS.

In Class B, though the risk from damage by mechanical injury may not be so great, the dangers due to the other causes referred to—viz., general dampness, moist vapours, corrosive salts in plaster, etc.—often cause much trouble in practice. It is often desirable in this class that the conductors be enclosed in plaster or concrete, containing a considerable amount of moisture and often corrosive salts. In such cases, the author has found any kind of split tubing without watertight joints very unsatisfactory, and faults often occur after installations of this nature have been completed and running for a few weeks. Of the present methods in use, the welded steel tubing already referred to, with screwed unions, appears to give the best results, and the cables should be drawn in *after the tubing has been fixed complete*, and the surroundings have become as dry as possible. Draw-in or inspection boxes have, of course, to be fitted in this case, and much inconvenience will be avoided in the future if these are left easily accessible so that cables can be withdrawn if desired. If let into plaster work, their lids should come flush with the outside layer, and should have some distinctive marking, or if under floors, a trap should be left to allow of easy access, and at the same time to mark their position.

Brazed Steel Tubing.

Steel brazed joint tubing has not been found satisfactory by the author. The brazing is often badly done, and splits at the least provocation. In this class of tubing, as with iron gas-piping, great care must be exercised in removing all burrs or sharp edges after cutting and screwing, also in insulating pipe ends and allowing ample room for conductors. The author has found in some instances that cables which were drawn into tubes with little difficulty required a considerable effort to withdraw them after a few years' time owing to the inside of the tube becoming rusted. If all elbows or sharp bends are strictly prohibited, however, the difficulty in drawing in or out is considerably reduced, but if unavoidable, they should be of the inspection type.

Wood Casing.

Wood casing, if well coated with shellac varnish, or other water-proof composition, may also be used in this class with success, but *non-waterproof casing should never be used,* owing to the objections already referred to in the case of insulated metallic tubing; and with wood casing, owing to its inflammable nature and there being no metallic sheath, these objections have much greater significance. Since the increase of pressure in the Newcastle district the author has heard of numerous instances of slight fires occurring through the use of unprotected casing in this class, aud one which came under his notice, and was, curiously enough, in a fire insurance company's office, demonstrates clearly that even a well-designed installation is not perfectly protected from a fire occurring from this cause. In the case referred to a leakage to earth of not more than one or two amperes at 240 volts was sufficient to make about 3 in. or 4 in. of 1½ in. diameter casing incandescent, and had any inflammable material been near at hand the result would probably have been a serious fire. This circuit was protected by a fusible cut-out on each pole. The fuse wire consisted of No. 22 gauge lead wire.

Non-Metallic Tubing.

The use of non-metallic tubing for inside conductors has, rather strangely, not made any great headway during the last few years. In the case of new buildings, earthenware tubes or ducts let into walls during erection would, the author thinks, make an excellent system of protection if this could be carried out to satisfy the requirements of a modern householder. This he is afraid, however, would not be easy to do, as the exact positions and arrangement of lights would obviously have to be fixed before the building is up. It would also be a difficult matter to fix additional lights after such an installation is completed, and the cost is probably much greater than that of metallic tubing. For factories and warehouses, however, these objections may not apply to such an extent, and the author would be glad to hear if any member has tried such a system.

Bitumenised Fibre Tubing.

A few years ago this was said to be the coming thing. Among the numerous advantages ascribed to it was that it was "impervious to moisture," "fireproof," and "rat-proof." The first and second are certainly not precisely accurate, as the author has on several occasions come across pieces of this class of tubing which have become quite "pulpy" after being a few years in a damp position, and it is fairly easy to ignite a piece of this tubing at a fire. It is evident, however, that for a short time this tubing will resist moisture, and it is also doubtful if any heat likely to arise from electrical causes would make it take fire, so in many respects this tubing shows distinct advantages over wood casing. The author has not tested the "rat-proof" qualities of this tubing, but is quite prepared to admit of its being offensive to the

digestive organs of this type of rodent. The greatest objection to bitumenised fibre tubing is its brittleness. A slight blow with a hammer, given accidentally when fixing, splinters it, and it cannot be bent to any appreciable extent. The method of jointing by means of thin brass sleeves is also defective, and tee-pieces and draw-in boxes seem unknown. It has already been noted that it is desirable and often imperative for the cables to be surrounded by a conductive sheath, so it is doubtful if any systems which do not fulfil this condition will ever be universally adopted, unless the insulating properties of the supporting or protective medium can be so absolutely relied upon that the use of insulated conductors is unnecessary.

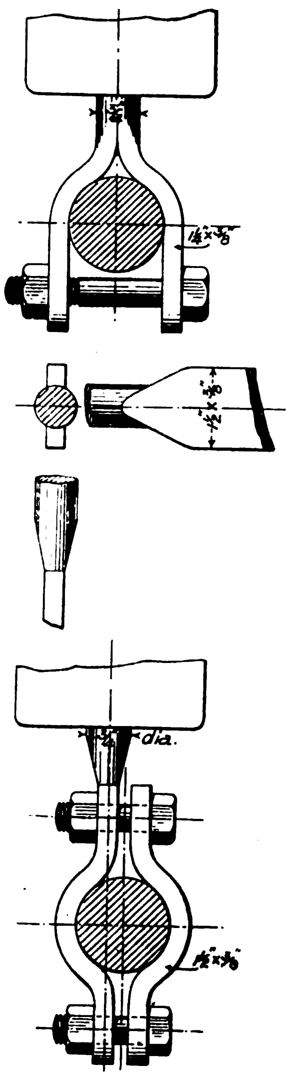


Fig. 1.

INSULATORS.

The foregoing remarks bring before our notice the use of insulators. These form an excellent method of supporting cables, and give protection from leakage due to moisture, but, of course, form no mechanical protection. In many cases, especially in workshop wiring, cables can be carried (except where led to or from distributing boards, motors, or lights) at such a height from the ground that all possibility of damage from this cause is avoided. Insulators in these instances are eminently suitable, and by reducing the cost of erection greatly enhance the "break-up" value of the installations. The various forms of insulators used and methods of fixing are so well known, that comment is unnecessary. A word may be said, however, in regard to the securing of heavy cables of 0·4 in. diameter or larger. These should be laid on a suitable grooved insulator, fixed so that the weight of the cable is carried directly by the insulator and not by fastenings, which are likely in time to wear or get eaten through and break. Exception to this, however, may be taken in regard to underground colliery workings, where it is sometimes advisable to have the cables secured in a comparatively flimsy manner to avoid them being broken or damaged by

falls from the roof. Porcelain buttons or cleat insulators in two halves, which grip the cable when screwed up, are very useful for small wires, and seem likely to come into use to a large extent in the future. A common fault in most of the cleat form of insulators is the exceedingly small screw holes allowed; this, however, is a matter which can easily be rectified by the makers. In large iron buildings without any woodwork, such as shipyard sheds, etc., not a little ingenuity has sometimes to be displayed in the fixing of insulators to the surrounding iron work. In an installation recently carried out by the author's firm at a large engineering works on the Tyne the mains were carried across the tie-bars out of the way of the travelling cranes by means of ordinary double-shed insulators fitted with special clamps instead of bolts (Fig. 1). These are very easily fixed, and make a sound mechanical job. All kinds of varieties of these clamp insulators can be obtained. Wooden battens bolted to girders or columns, or iron brackets, such as shown on Fig. 2, may be used for securing the smaller wires when button insulators are used. There is another advantage to be derived from the use of insulators—viz., the wires can be traced by the eye and faults generally seen. Moreover, when discovered, they can be easily rectified without having to withdraw the wires from tubes or to cut open walls or floorings, etc. Although, at present, insulators are used only for workshops or plain buildings, the author sees no reason why a modified form should not be used for better-class buildings and private houses. On the Continent the author understands a large amount of lighting wiring has been carried out by means of twin flexible wires supported by insulated clips. This method would certainly reduce the cost of the wiring considerably, and if twin conductors heavily insulated were used instead of the ordinary thinly-insulated flexible, this system should be perfectly sound.

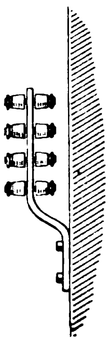


FIG. 2.

CLASS C.—UNEXPOSED POSITIONS.

Our old friend wood casing, which has been in existence since the earliest days of the commercial application of electricity, has on several occasions been condemned as obsolete by eminent authorities. In spite of this, however, it still exists, and, personally, the author regards this method as being equal to many at present used for this class. While the objections referred to in Class B condemn it in any but perfectly dry places, in old buildings, especially large houses and offices where it would be inconvenient and difficult to place the wiring out of sight, casing is still an easy method of enclosing conductors, and makes a neat-looking job.

SPLIT TUBING.

Light gauge tubing of the "Simplex" class, with what is termed "close" joint, but which the author would prefer to call "split tubing,"

as the term "close" joint is certainly inclined to be misleading, is also used in this class, and is regarded by some as a more mechanical system of wiring. The tubing being jointed by being simply pressed into tapered couplings, enables it to be fixed at about half the cost of screwed joint systems. This class of tubing, however, requires rigid support, as it is very much inclined to work loose, especially at bends and tees, and this gives the job a very shoddy appearance. Saddles should always be used in preference to pipe hooks for this purpose. On the whole, the author does not think this system has much to recommend it, except, perhaps, that it can be fixed by less highly-paid men than can wood casing.

Lead-Covered Wiring.

Lead-covered cables clipped direct to surroundings by brass saddles is, in the author's opinion, a much better method than either of those referred to, and combines the advantages of simplicity, reduced cost of erection, immunity from moisture, and easy localisation of faults. From an æsthetic point of view this may be objected to, but if the wiring is carefully carried out and runs kept perfectly straight without sagging, the appearance is as good as wood casing or tubing on the surface. Some excellent work of this class has been done in ship-lighting, and probably the reason why this method has not been more generally adopted for buildings is to be found in the conservatism of fire office officials, and, one might also add in some instances, supply companies' regulations.

Flexibles.

The protection of flexible conductors in unexposed places, is, perhaps, more a question for cable manufacturers, as it largely depends on the materials used for covering them. In exposed places, however, this matter sometimes needs special attention. It is desirable in such cases to limit the amount of flexible used as much as possible, and the vast improvements, or, perhaps, one might call it enlightenment of the electrical fittings' manufacturers during the past two or three years, has led to this being practicable with any fittings likely to be used in this class. Portable lamps, however, are often required, and these being probably subjected to more rough treatment than any other part of the installation, faults frequently occur in the flexibles attached to them. After experimenting with various kinds of armoured flexibles for shipyard use, the author found that the ordinary workshop class enclosed in flexible bronze or steel gas-tubing gave the most satisfactory results, and, with the exception of being somewhat costly, this method appears to be suitable in most instances where extremely rough conditions are experienced. In ordinary cases armouring composed of galvanised steel wires or steel braiding is sufficient to protect the flexibles from being cut or damaged by rubbing against rough bodies, but as oil has a very rapidly destructive effect on them, the tubing method will be found much more reliable if there is any chance of the cables coming in contact with the substance.

Question of Cost.

In ascertaining which is the most suitable method to be adopted in each class, the question of cost demands careful attention. Reference has already been made to the excessive cost of erection; in some instances this very nearly equals the value of the materials used. An analysis of the cost of the various methods referred to in this paper would, therefore, be interesting, but in endeavouring to obtain this from actual instances, the author found it impossible to make anything but a very approximate comparison owing to the great variations in the conditions of the different cases. The figures, therefore, of the accompanying table must be taken only as representing the average cost per point for erection, support, and protection of conductors in installations which have come under the notice of the author during the past three years.

Approximate Cost per Point Single Light Wiring Inside Buildings.

Method and Class.	Materials.		Labour.		Total.	
	s.	d.	s.	d.	s.	d.
Iron gas-barrel ... ... A	13	0	12	6	25	6
Screwed welded tubing ... ... A	13	6	10	0	23	6
Armoured cables ... ... A	9	0	8	0	17	0
Insulators ... ... B	6	5	5	2	11	7
Painted wood casing ... ... B	7	6	6	0	13	6
Ordinary wood casing C	6	7	6	0	12	7
Split steel tubing C	7	0	6	0	13	0
Lead-covered wires (clipped direct) C	5	9	4	6	10	3
Insulators (cleat type) C	5	6	3	9	9	3

It will be noticed there is a considerable difference in the cost of erection between screwed and unscrewed tubing, the latter costing about half as much to erect as the former. Whilst this is owing partly to the amount of time taken in cutting and screwing the heavy-gauge piping, it must not be overlooked that very unfavourable conditions of working generally exist where this class of tubing is used. When armoured cables have been used by the author, however, the conditions have been similar to those in which screwed tubing has been used. Thus it will be seen that a very considerable saving is effected in the cost of an installation of this nature. In Class B the additional labour required for screwed tubing compared with wood casing or insulators is still noticeable. In Class C the cost of cleat insulators and lead-covered wires clipped direct come very near to each other, and both are easily removed if required. Conditions vary so greatly in regard to the surroundings of electrical installations that the author feels it would be imprudent for him to define any system as alone being suitable for any of the classes referred to. Generally

speaking, however, he is of this opinion: That for Class A some form of armoured cables will in the near future be adopted as a standard for this class. For Class B he is of the opinion that for surface work, waterproof painted casing, and for covered wiring behind plaster work, screwed welded tubing are the most satisfactory methods. For Class C either cleat insulators or lead-covered cables, according to circumstances. Insulators other than this type may be taken almost as a separate class and form, as already mentioned, a highly efficient method in the class of buildings suitable for their use.

In the event of dismantling and taking down of conductors, insulators undoubtedly stand as the method which gives greatest facilities and highest value for old material, and this is sometimes a matter of importance in carrying out an installation which is to any extent of an experimental nature. Wood casing, though not as expensive to erect as screwed tubing, is practically of no use after being taken down, and it costs more to dismantle than the value of material recovered. Owing to the few instances he could refer to, the author was unable to obtain any reliable data in regard to the cost of taking down cables fitted in accordance with the methods referred to, but it is obvious that with piping the conductors would be more likely to be damaged or cut into short lengths than with armoured cables, and consequently to be of less value as old material.

The author hopes these somewhat brief and incomplete descriptions given by him of a few of the methods in general use will have been of some interest, and he trusts that this paper may open the way to a full discussion of the subject which will tend towards greater uniformity in methods in supporting and protecting inside conductors.

Mr. J. H. HOLMES (*Chairman*) said that the paper was one which lent itself to a good discussion. As Mr. Falconar had mentioned his name as having sent a board of samples, he would like to tell the members how the tubing to which the author of the paper referred was made, he having seen it manufactured both in America and Germany. In the former country the interior conduit system was largely used. The tubing was made out of long strips of paper rolled round and round, one in one direction and another in another, until the requisite thickness was obtained. The tubes were cut up and dipped end-ways into an asphaltic composition. It was quite hot when dipped, and it dried and formed very solid. He did not think tubing got pulpy when made in this way. In America they found the tubing liable to damage mechanically by people putting nails through it, and they therefore provided it with a steel covering. Mr. Holmes

The American system differed from that of Germany, for in that country Mr. Bergman made it on quite a different plan. He made the tubing out of very good quality thin sheet steel, which, after bending, was brazed. The steel tube was made a little larger than the asphaltic tube, which was placed inside. The steel tube was then actually drawn down on to the asphaltic tube (which was somewhat longer than the steel tube), during which process the steel tube got smaller in diameter and greater in length until the asphaltic composition made a very firm lining.

Mr. Holmes. The unions were also a very fine piece of work, and were actually cold-pressed out of sheet steel. The brass-covered tubing was similarly made. Bends at any angle were easily obtained by the use of a tool. He noticed Mr. Falconar suggested the use of lead wire for making joints in the tubing, but he did not quite see how this could be used.

Mr. Woodhouse. Mr. W. B. WOODHOUSE said that his experience of split tubes had forced him to the conclusion that such tubing should not be used where there was any moisture; L-pieces should never be used. He found a cheap construction was gas-barrel, screwed into cast-iron junction-boxes, which, if properly supervised, could be made watertight; much of the trouble with internal burrs arose from using pipes too small for the purpose. Wherever possible he preferred to use clip insulators; for small wires the button insulators were excellent, but the weak points of such wiring seemed to be at the switches and ceiling roses, for with the fittings now on the market it was necessary to mount these on wood. He suggested that these fittings should be arranged like the clip insulators, so that a rose might be fixed straight on to iron work and yet have the wires surrounded by porcelain. With reference to the double-shed insulators, the speaker disagreed with such construction, because it needed binding wire, which he considered an abomination. He sketched a type of insulator made by the British Thomson-Houston Company, which could be mounted singly or in rows in a very cheap and effective manner: it was suitable for all cables larger than 7-18s, and although the cable was firmly gripped by the insulator it was easily removed. With reference to the use of flexible metallic tubing for protecting hand-lamp leads, his experience had been that such tubing was not oil-tight, and on account of its strong appearance got very rough treatment, which caused it to break and cut into the lead. He preferred to use ordinary workshop flexible, with a heavy outer coating of jute and a protecting iron wire; this was fairly strong, would stand a considerable amount of oil, and was cheap to replace. In places where much oil was to be met with, lead-covered wires were the only wires that could be used, but the oil always got to the end of the lead, at the switch or lamp fittings, and he met the trouble by sealing in the conductors in a porcelain or metal box, just as in a cable dividing box.

Mr. Newitt. Mr. L. NEWITT said he had very little to do with contract wiring himself, but, at the same time, was anxious to know what others had done. On reading over the paper he had not discovered that any one of the systems described was perfect. For example, if we took any one of the systems requiring steel tubing, we put ourselves very much in the hands of the plumber or engineer, who had to screw and fit up these pipes, and it was often found that a sharp rag was left on the piping, which tore the insulation off the wires; or the pipes were not watertight. Also, if piping were used, we had to consider the increased cost of the installation which, when work was undertaken at about 12s. per light, would not leave sufficient margin for doing really good work with piping. It had also been noticed that in some cases condensation in the pipes occurred, and then it was only a question of time before the installation broke down.

Mr. Newitt.

With regard to the remarks on rat-proof cable, he had heard it said that rats never bit tubing unless they heard water running inside of it; so that they need have no fear on that score.

With reference to the tubing which was insulated on the inside, it was almost impossible to retain the insulation intact around bends and joints where it was particularly required, and in fact any piping that could be used did not appear to be entirely satisfactory.

As regards wood casing, he (Mr. Newitt) quite agreed with the writer of the paper that, except in isolated cases, it was not to be recommended. Personally, he thought that the more wires were exposed the less likely they were to cause trouble, provided that at points where they were liable to external injury they were protected by a suitable guard. To illustrate how a system of wiring without casing or tubing could be carried out, he had brought with him a complete model of a section of wiring, showing how a friend of his had fitted up his building, and he trusted that some of the members would give their opinion on the arrangement.

As regards this proposed system of wiring, it was possible that the Insurance companies might have some objection to the arrangement, but if the matter was thoroughly taken up by the proper authorities he thought there would be no difficulty in getting the necessary addenda to the rules of all insurance companies. This system was recommended for its simplicity, cheapness, safety, the absence of all soldering, and the ease with which extensions could be made if found necessary.

Mr. Heaviside.

Mr. A. W. Heaviside said that one gentleman had referred to Prof. Silvanus Thompson's description of the ideal tubing, but he thought he had left out the expressions pick-tight and hammer-tight. It appeared to him that the most important thing was the insulation; why trouble about condensed moisture, except, perhaps, in dealing with shipwork? A man who had had experience of shipwork could do almost anything. With regard to the various methods, it seemed to him that everybody was trying to find out which was the cheapest, and we should eventually settle down to three or four types. The greatest problem of all was the bad workman, because his workmanship was bad and he created a bad impression. He not only injured the house, but had no regard for the comfort of the householders.

Mr. Little.

Mr. F. Little said he had had a good deal of wiring experience. He noticed Mr. Falconar did not refer to the earthing of any system, particularly of lead-covered systems. It was important, where the ceiling roses and switches are fixed, that the lead covering should be metallically connected by some means. He had used the single lead-covered wire, and he thought it a very good system—especially underneath floors, or in difficult situations where bends were numerous. He was of the opinion that in all cases tubing systems should be properly earthed. A little time ago two men were killed through inefficient earthing of tubing. Had it been properly earthed this would not have occurred. He thought the system introduced by Mr. Bathurst was a very good one.

Mr. Hanks.

Mr. F. T. Hanks said that Mr. Falconar, in discussing gas-barrel,

Mr. Hanks. had mentioned that it had a want of flexibility. If necessary to make this flexible, it required a great deal of labour, which should be avoided as much as possible on account of cost. In regard to internal roughness, this tubing could now be obtained without this disadvantage. It was not a practical suggestion to drive an iron bar through a gas-barrel to remove the internal roughness. He could understand a "rimer" or "cutter" being used for the purpose, but it would be very bad for the "cutter." A man who was a mechanic should not have any trouble in making watertight joints in gas tubing.

He did not understand how Mr. Falconar intended to use spun yarn, asbestos twine, or lead wire in making watertight joints—unless he used lock-nuts.

With reference to internal moisture, a solution of this problem was very badly wanted. The life of a cable was no doubt shortened by water getting into pipes. He could not suggest a remedy, unless it were by lining iron or steel pipes. He thought that, if they were lined, condensation would not be so likely to take place, as moisture did not then come into actual contact with the internal surface of the pipes. The threads which were put on the ends of welded steel tubing were rightly condemned by Mr. Falconar. It was a great nuisance to have to procure special tools in order to get the special threads required. He did not think screwing at all necessary on many classes of installations. He thought slip joints were quite good enough and much less costly in cases where there was no necessity for much strength, and would propose that the ends of the tubes and the insides of the sockets be covered with a hard-drying varnish, This would make a good and lasting watertight joint. There should be no difficulty in obtaining a suitable compound which would ensure an electrical connection through the joints.

At the end of his paper Mr. Falconar favoured armoured cables for use under Class A. What is wanted is a cable which would meet all conditions in practical work, but the difficulty was to get an armoured cable to meet the many requirements. For instance, it would not be at all practical to use steel-taped cable if many sharp bends came into the run, but he thought such a cable would be very serviceable for long runs without many bends. Ordinary wire-armoured cabling answered well for ship work, but it had the objection that if moisture, especially sea-water, got to the galvanized steel wires, it deteriorated them in time, and if examined after a while they were generally found to have become a mass of rust. If armoured cabling were well painted, the paint would afford protection for the iron armouring, and that in turn to the internal part of the cable, and would make a lasting job. With regard to non-metallic tubing, he did not think Mr. Falconar's suggestion to run earthenware tubes or ducts, let into the walls, was a very practical one, and he thought the question would have to be very carefully considered before this suggestion was adopted. Bituminous fibre tubing was, he thought, rightly condemned. It was not a good material at the best, and there was always the likelihood of nails, etc., being driven into it.

Mr. Falconar rightly condemned simplex, or split tubing, as he

called it. He (the speaker) thought if tubing had to be used, it should be welded tubing—not split or brazed. He thought, where stronger mechanical protection was not required, lead-covered wiring was one of the best systems for carrying out an installation, as such wiring could be made watertight more easily than any other system. He had in mind an installation carried out in some extensive greenhouses, where a lead-covered cable system was made absolutely watertight. A twin lead-covered cable was used and worked admirably. The tin-lead boxes into which the wires were brought had the leading-in holes drifted so that the cables fitted exactly, but white-lead paint was applied to the ends of the cables before being inserted. It made a very neat installation, and successfully withstood the water. The fittings, as well as the entrances to the switches, etc., were, of course, made watertight. Mr. Hanks,

He would have liked to see more reference made in the paper to the protection of the conductors at the terminals, where the switches, etc., came, because he thought breakdowns were in most instances caused by faults, etc., at the terminals rather than in the general run of the cables, and he rather wondered Mr. Falconar had not given greater prominence to this point.

With reference to Mr. Falconar's remarks to the effect that a form of armoured cable would at some future time be adopted as a standard, he did not agree with the writer for the reasons stated. He did not think an armoured cable would be manufactured that would meet the many demands which cropped up in ordinary practice.

He was still very much in favour of wood casing for surface work in dry places, but the grooves should be coated with shellac varnish and the casing well painted on the outside. He wondered owners did not take more care of their installations as regards the painting, etc., of casing or cables generally. In many cases the ordinary woodwork was seen to be well painted and the casings, tubes, etc., allowed to go without any such covering.

For Class C Mr. Falconar favoured cleet insulators or lead-covered wires. For his part, although he thought lead-covered wires would make a very neat installation, he would not favour their use on plaster work. He foresaw much trouble in fixing such cables because plugs must be used in many cases. This would be costly as regards labour, and as the cables would not cover the ends of the plugs the latter would look unsightly.

With regard to the question of cost, he did not see why Mr. Falconar made any reference to the value of the material after an installation had been dismantled. If it were foreseen that the installation was to be of a temporary character, very little pains need be taken in putting it up, but care would of course be taken not to injure the material more than could be helped.

Mr. G. Ralph said one of the previous speakers mentioned having used flexible metallic tubing for wiring big engines. It might be of interest to know flexible metallic tubing, made from solid drawn tube, could now be obtained, which was of course impervious to oil and water, and which would therefore seem very suitable for this purpose. Mr. Ralph.

Mr. Woodhouse.

Mr. W. B. WOODHOUSE said that the tubing to which Mr. Ralph referred was about twice the price of the ordinary sort.

Mr. Gowdy.

Mr. S. H. GOWDY was of the opinion that the time had not yet come for standardisation. Each method had its advantages and would retain them for some considerable time to come, but insulated steel tubing would eventually be adopted, possibly a more flexible tube than we are accustomed to use at the present. He considered that for damp places, lead-covered wires in screwed welded tubes, or lead wires in wood casing painted with shellac, made a very sound job. Non-metallic or papier maché tubing is of little use unless it can be fixed so as to be absolutely free from the joiner's hammer. Ordinary wood casing is not done with yet, and is probably still more used than any other system for protecting wires. Plain uninsulated tubing has both its advantages and its disadvantages. In case of the former, should a short circuit occur between two wires of opposite polarity they will probably burn themselves out and prevent any further danger; whilst, in the latter, dampness is not easily got rid of, thus increasing the trouble of earth leakage, the sweating acting upon the insulation detrimentally. Professor Silvanus Thompson had defined an ideal system in a nutshell when he said it should be electric-tight, water-tight, air-tight, gas-tight, oil-tight, and rat-tight. Therefore, what is required is a perfect insulator mechanically strong and impervious to moisture, acids and alkalies of cements and plasters used on buildings. With reference to the estimates and cost of the different classes of tubing and casing mentioned in the paper, he would like to have fuller details as to what they include, and how Mr. Falconar arrived at them, as the price seemed very high in some cases. He was of the opinion that screwed welded steel tubing was the only satisfactory tubing yet introduced, though it was more expensive both in first cost and in erection. He considered there were far too many different patterns of tubing accessories, and that there was a great want of standardisation both in these and in the sizes of tubing itself, and in support of this gave some details extracted from lists of various manufacturers who seemed to vie with each other as to which could provide the largest instead of the smallest number of fittings. Some made use of outside dimensions, while others only gave internal measurements, while others again listed their goods alphabetically.

Mr. Gott.

Mr. A. E. GOTT said that there was no doubt some form of piping system would be the system of the future. If there were multiple control and separate wires going to every lamp in the place, these wires would have to cross each other, which would add to the difficulties of installation. The weakness of any pipe system was the absence of any recognised method of running pipes along the wall and under the floor. The boxes of all these pipe systems seemed to be too shallow. Pipe systems to be satisfactorily installed should be let into the brickwork before the plaster was laid on. Lead-covered wires had failed in many installations because pure lead was used. Some lead alloy was wanted to replace the silver in the old-fashioned lead. A large firm of shipowners had taken out their entire lead-covered installations on board their ships, and had used vulcanized wire with great success.

He remembered the first system he installed, where the conductors were buried in fireclay—to prevent them taking fire. They also used casing three sizes too large. This was done most religiously. The system was still running and there had not been a fire. Mr. Gott.

The success of any system depended largely on the question of labour. The electrical trade suffered from imperfect labour. Every man who was a failure in every other trade came to them, and thus jobs were spoilt by ignorant men. He remembered the case of some bad work on a ship. The cables were run along the lower deck, were plain cotton covered without rubber or compound, and every time a sea came down the companion-way there was a short circuit. This vessel, which was an oil-tank vessel of the old type, was destroyed by a terrific explosion, and a man who was in the hold at the time had not been seen since. There was no doubt a spark caused all the trouble.

Mr. C. F. Proctor said the question was really one of cost. He believed that a cheap quality of iron pipe could be obtained from manufacturers. He was also of the opinion that the architect was the cause of much of the trouble, as he did not take into consideration the wiring when designing the building. He knew of several cases where great and unnecessary expense had been caused through this oversight, no attention having been given to how pipes could be run without encountering thick walls, thus leading to the making of numerous bends and joints which might have been avoided. On the whole, he thought the iron pipes one of the safest and best methods. Mr. Proctor.

Mr. R. Robson said wood-casing was very hard to beat for old houses, and it was certainly the thing for the poor man's house because of its cheapness. Mr. Robson.

Mr. A. W. Heaviside said it was a very important question, as where a public supply company expended capital to the extent of £100,000 the public had to spend £50,000 on fittings, and that was not in the case of a well-developed company. For every £100,000 spent by the company the public would probably have to spend an equivalent amount in the wiring of their houses. Mr. Heaviside.

Mr. Falconar, in reply, said: The Chairman, at the last meeting, made some comments on the tubing system. He would like to know a little more about the method of drawing the tubing exhibited. Was the steel covering drawn on cold? [Mr. Holmes: "Yes."] Mr. Holmes also made some remarks about the methods of jointing proposed. With regard to asbestos twine, the idea was to wind it after the tube had been screwed; if wound round the thread before sockets were screwed on a fairly good watertight joint was obtained. Mr. Woodhouse confirmed his remarks about simplex tubing; he also advocated ceiling roses without blocks. The worst part was where the wires were run under the ceiling rose; he had seen several ceiling roses made with grooves or holes going through the porcelain base. With regard to lead-covered wiring in flexible tubing, he had not tried it, but imagined the lead covering would give way. Mr. Falconar.

He had some very scathing remarks to make to Mr. Sleigh, who rather took the wind out of his sails by bringing a sample of standard

Mr. Falconar.

tube, from which he demonstrated that the apparent discrepancy in his remarks was due to the present imperfect method of measuring gas tubing. Mr. Sleigh recommended taped wires. He had tried these once, but they were not very successful. The tape did not seem to be sufficient and moisture got in.

Mr. Little made some remarks about earthing, and he entirely agreed with him that any metallic tube system should be continually earthed through the entire length.

He was obliged to Mr. Hanks for his long criticism of the paper. With regard to the method of producing a smooth interior in the tubes, he did not see how Mr. Hanks could get a cutter or rimer right through a long tube.

With regard to jointing tubing, his reply to Mr. Holmes applied to Mr. Hanks as well.

With reference to sleeve-joints, these would certainly be very good where the piping was rigidly fixed, but he found them in most cases apt to work loose (there was a sample on the board).

With regard to the sketch on page 841, it was not meant to represent petticoat insulators; they were bobbin insulators, and were for inside, not for outside use. Mr. Hanks mentioned something about junction-boxes lined with mica, but he had not had a very satisfactory experience with it, as it absorbed moisture.

Regarding waterproof casing, his idea was to prevent the water from getting in. He agreed with Mr. Hanks that good insulation was obtained when the casing was shellac-coated, with a coat of paint over all. In one case he had in mind the test came out excellently, although the building was very damp.

The value of old materials was a point to be considered. If the wiring could not be taken out, or was worthless when this was done, the user would have to write off a large amount of the cost as establishment charges or otherwise. If there was some method by which wires could be taken out easily they would then make a valuable asset. Mr. Gowdy evidently thought screwed tubing the best. He would like to know what sort of tubing Professor Silvanus Thompson suggested after giving his definition of his ideal conductor.

With reference to Mr. Robson's recommendation of wood-casing, his attention had been called to some remarks on this subject in the *Electrical Review*. He was gratified to see they considered his paper deserved the careful criticism they had given it, which, on the whole, was favourable, but they mentioned he seemed to have a soft corner in his heart for wood-casing. His experience of wood-casing had been the same as Mr. Robson's, very favourable. They also condemned him for having divided his subject into more than two classes; one class, the worst, was the only one necessary. But if you were to do that, it meant practically abolishing the electric light from half of the consumers who could not afford to pay the cost of wiring for this class.

With regard to damp caused by bad state of property, this was a matter for the property owners to attend to.

NEWCASTLE LOCAL SECTION.

SOME NOTES ON CONTINENTAL POWER-HOUSE EQUIPMENT.

By H. L. RISELEY, Associate Member.

(*Paper read at Meeting of Section, February* 16, 1903.)

In response to your committee's invitation to submit a paper to the Local Section, I have thought that a few notes on the subject of Continental power-station practice gathered during a visit to the Continent last September might be of interest, especially to those who agree with the writer that there is much to be seen worthy of consideration, if not imitation—of course, subject to improvement. Some little interest may also be attached to a few of my notes in view of the Institution's Continental trip this spring.

On first entering a Continental power-station, one is struck especially by the apparently extravagant amount of space which the switchboards and accessories occupy in the majority of central stations abroad. On closer inspection and consideration one finds that this is not without an object; the object being primarily to provide for any contingency which may arise, and always to provide a duplicate method of operating in event of any part of the switching apparatus being deranged by accident.

A system nearly approaching the ideal was represented, in my opinion, by the central station at Paderno, twenty miles from Milan, which may be of interest, as it is to be visited during the Italian trip of the Institution next April. There are seven turbine water-driven generators, having a capacity of 2,160 H.P. each, and the machines a capacity of 1,590 k.w. each, speed of 180 revolutions per minute, frequency 42 per second, 13,500 volts. The current generated by the alternators at Paderno is collected at the 'bus-bars, and thence led to the high-tension transmission line without the intervention of any transformers. At Milan the line ends at the Porta Volta station, where the pressure is transformed down to 3,600 volts, and at this station steam-driven generators are running in parallel with the transformed current generated at Paderno (Fig. 1).

The switchboard at the central generating station at Paderno is arranged in a large central opening in the wall, covering an area of 1,750 square feet (Fig. 2). The apparatus for controlling the generators is divided into nine panels, seven of which are for the seven generators, and the two panels in the centre serve for collecting the two sets of 'bus-bars and for placing wattmeters, etc. The attached sketch shows a complete diagram of the generator switchboard, board for the trans-

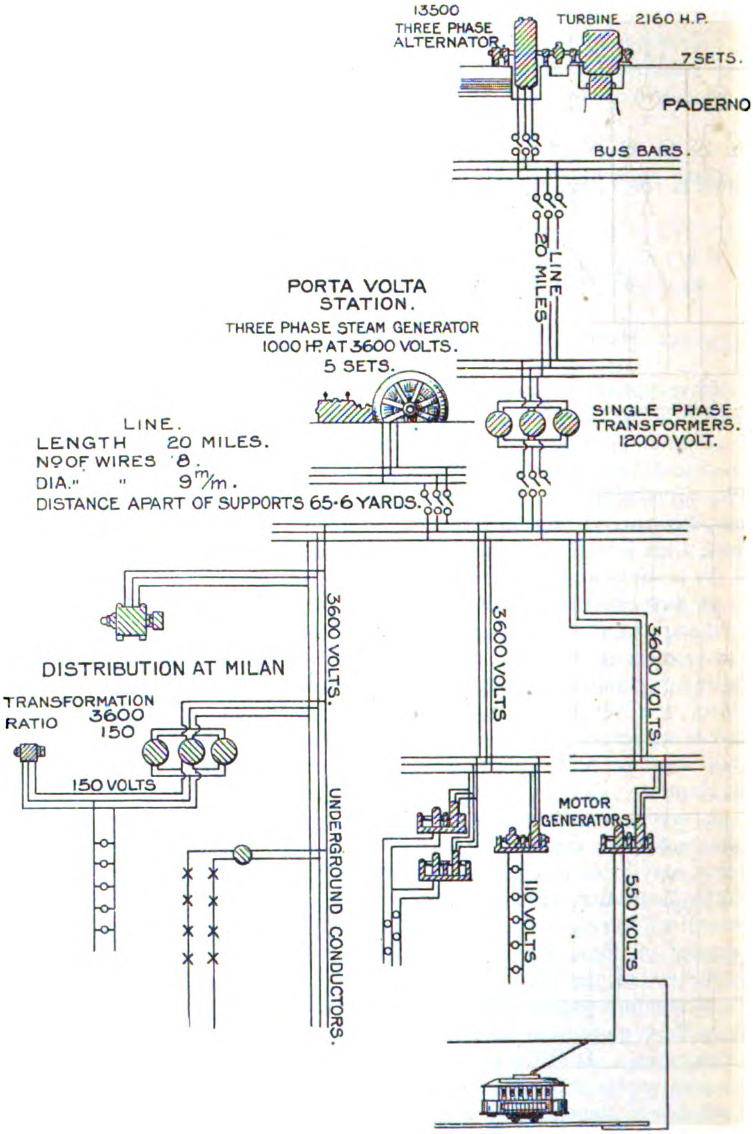


FIG. 1.

mission line, and feeder panels at Milan. Each of the generator panels comprises one triple-pole oil-break switch, three fuses, one linking-up device, one rheostat for field, one rheostat for exciter, one instrument transformer, one voltmeter and indicating wattmeter, one synchronising voltmeter and lamps. All the machine rheostats can be worked in

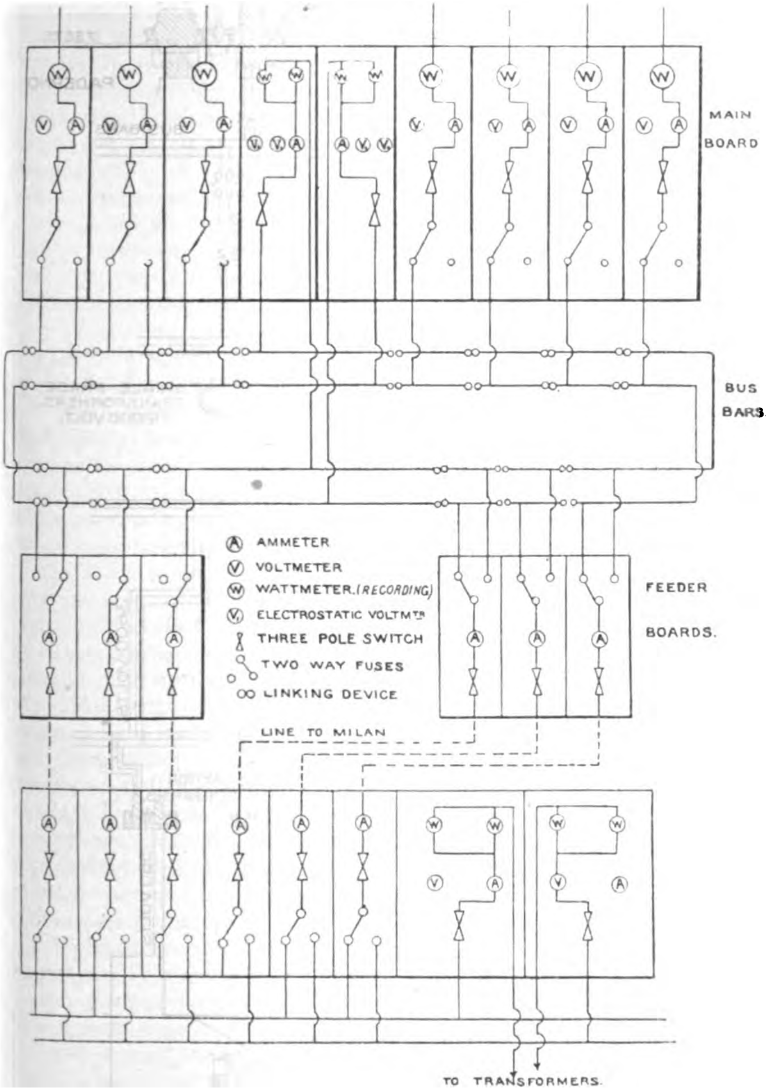


FIG. 2.

parallel or not as desired. The link devices serve the following purpose: The whole of the installation from Paderno to Porta Volta, the auxiliary generating station at Milan, and sub-stations had to be arranged so as to enable the two services to be separated at any moment into two distinct systems. For that reason the 'bus-bars are arranged in two groups, and each generator may be switched on either group;

in that way the lines can be separated. The steam plant at Milan and the generators at Paderno can also be separated. It was also arranged to provide for the possibility of separating one of the services from the other, in case that service should have any special requirements on account of its disturbing influence on the other services. However, the experience at Paderno has proved that it has not been necessary to separate the two services. Behind the series of high-tension generator panels are arranged in another room the high-tension transmission line boards, each line having a special switchboard, with switch, link device, voltmeter, and ammeter. All the switchboards are extremely accessible. Each panel may be entirely separated from the live ones, so that it may be attended to and cleaned by the attendant in perfect safety. The panels are, as usual in Continental practice, made of marble and porcelain fixed on iron supports, no combustible material being used in their construction. The connections are all rigid bars, and the whole is a perfectly symmetrical, simple, and extremely mechanical job. The high-tension transmission lines, before taken out, are led into the floor above, in which are arranged the lightning arresters. Thence they pass through holes in the wall to the first pole. The lightning arresters are of the usual Wurz type, and comprise a number of cylinders made of special brass containing a large quantity of zinc, arranged so as to leave about 0·04 in. gap between each cylinder.

In my opinion the advantages of this type of board are its extreme accessibility and safety in having, so to speak, another way round, everything being in duplicate. Each portion of the apparatus can be made dead for cleaning or overhauling purposes without the slightest danger of interrupting the supply. The type of board which is the favourite in this country for high-tension alternating work is sometimes referred to as the multicellular type. The chief faults in connection with this type of board are that it is too cramped, the 'bus-bars being far too close together, and there being no second way round. Also, it is very difficult to keep clean, as the insulators at back of 'bus-bars get covered in hot engine-rooms with a greasy deposit of dirt, which it is impossible to remove by means of air blast, and it is obviously not very safe to try and clean a live board by means of dusters, etc., as you then stand a good chance of starting an arc between two bars, besides being a danger to the man employed. Again, the switches are too cramped. It is not an uncommon thing for the switchboard attendant when about to synchronise to put the switch a shade beyond half-cock, and to make contact to the bars with disastrous results.

Kander Power-house.

As the first full-gauge electric railway was supplied from this power-house, I think a short description will be of interest. It is situated near the junction of the Kander with the Simmen, quite close to Lake Thun, and was entirely equipped by Messrs. Brown-Boveri. Its primary object, as stated, is to supply power to the Burgdorf-Thun line. At present about 3,600 H.P. are converted into electric energy, but

provision has been made for increasing the capacity of the station to 4,500 H.P.

The power-house is situated on the bank of the lake, and is 108 ft. by 37½ ft. wide, and has room for six turbines and generators—up to the present five have been installed. The turbines are by Girard, of 900 H.P. each at 300 revolutions per minute, and the speed can be regulated by hand or automatically. The three-phase generators are connected direct to the turbines, having each a rotating field spider with 16 poles, and develop each 620 k.w. at 4,000 volts. The drop is 18 per cent. up to 115 amperes at 4,000 volts on an inductive load, necessitating an increase of 38·7 per cent. in the exciting current. In view of the fact that the whole output of a machine has to be used at times on a single-phase lighting circuit, they are designed in such a manner as to enable them to develop their full power of 620 k.w. at 4,000 volts as single-phase machines. In that case, with a non-inductive load, the drop amounts to 9·1 per cent. Each of these generators is separately excited by a four-pole exciter of 12 k.w. at 60 volts, the armature of which is mounted on the main shaft. These direct-current machines for exciting the three-phase generators receive in their turn current for exciting their fields from two other direct-current machines separately driven by turbines each 20 H.P., developing 14 k.w. at 125 volts at 850 revolutions per minute. The reason for this indirect way of exciting is that the fluctuations in the speed of the main turbines, due to the variation of the load on the generators, have less influence on the pressure than if the field of the exciter was to decrease simultaneously with the speed of the generators and exciters. The field regulation of the generators can be effected either separately or in two groups or else all together, as desired. It is done entirely by means of the secondary exciting circuit. Any alteration of the resistance in the circuit of the secondary exciting machine is avoided by suitably arranged rheostats, which are switched on automatically during the regulation, so that in any case these secondary exciting machines always remain under constant load both during the regulation itself and after switching in and out of the fields of any number of generators. As the current to be supplied by these secondary exciters does not exceed six amperes, it was possible to arrange the rheostats very neatly. The shunt-breaking resistance of the exciter switches was arranged with an adjustable air-gap. The terminals of the generators are coupled up by small cables, arranged in small tunnels which are quite accessible to the main switchboard, which is of the usual Swiss make with a facing of white marble.

The main switchboard itself is in another room adjoining the main building, 50 ft. by 15 ft., and is supported from the ground on rolled-steel joists about 9 ft. 6 in. up. On this board, which fronts the engine-room, are fixed all the necessary instruments and regulating resistance wheels, switch levers, etc. At the back, in the other room, under the floor, are arranged the 'bus-bars to which are run the generator cables. There are no 'bus-bars fixed to the switchboard itself, and all conductors on any panel may be disconnected from the 'bus-bars by removing the links at floor-level. The 'bus-bars are

divided into two sections, so that it is possible to operate two circuits, which are called steady and unsteady. The two sets of 'bus-bars are arranged in a circular fashion, so that either can be closed or open at certain points. In this way it is possible to work the two circuits either separately or together. At the time of my visit the bars were divided, the unsteady service supplying current to the Burgdorf-Thun line, the other supplying all the rest. Arrangements have been made to enable the two circuits to be worked together in case of any breakdown of apparatus. The central panel of the switchboard contains a switch lever for connecting the two 'bus-bar systems. The regulation of the two separate services (which was extremely arduous, due to the great head of water, and being unable to govern well) is affected according to the requirements, as shown by the two 'bus-bar voltmeters arranged at each end of the switchboard. In order to enable the generators to be used in any desired combination for the joint or separate working of the two services, the driving devices for the regulating rheostats are capable of being coupled up all together or in two groups as desired, so that they can be operated by the two large hand-wheels directly under the voltmeters. Adjoining the generator panels at each end is a panel for connecting the two sets of 'bus-bars with transformers which transform the pressure from 4,000 volts up to 16,000 volts for transmission. Places in the immediate neighbourhood are supplied direct from the 'bus-bars at 4,000 volts.

Under the switch-room is a transformer-room, in which is an overhead crane, which can be travelled into a repair shop. The transformers on being taken out of the repair shop are lifted on to a bogie car on rails, and are transported along rails laid across the whole transformer-room to their place. They are slid off the bogies on to rolled-steel joists sunk into the concrete, just projecting about ½ in., and thus it is very easy to change the transformers in case of any breakdown. They do all their transformer repairs at this station. At each side of the transformer-room there is space for nine transformers. Up to the present only eight have been installed. They are single-phase transformers immersed in oil, and water cooled, capacity of 300 k.w., the efficiency being 98 per cent., star connected. Four of these transformers are on the steady circuit, two of which are devoted entirely for lighting and are operated in parallel, being connected to the single-phase circuits. The other two are used for power. The other 'bus-bar system, called unsteady, has three transformers coupled up with a fourth in reserve, which is capable of being switched into any desired phase by means of special switches in the primary and secondary circuits.

All conductors, including the high-tension conductors from the terminals of the transformers, are taken through the ceiling into the transformer switch-room situated above. Insulation through the floor is ensured by very thick glass tubes about 20 in. long. In the transformer switch-room are arranged in a clear and easily accessible manner all the switch levers and instruments for the primary and secondary circuits both for the transformers and transmission line. The 'bus-bars of the two services are each led along the longitudinal

side of the room, and the switch apparatus for the primary circuit of the two groups of transformers is accordingly arranged at both sides of the room, being separated in accordance with the two services. Each transformer has a switch panel of its own, containing oil-break switch, ammeter, and fuses. Opposite these, in the centre of the room, are arranged 'bars and switches for the high-tension circuit of the transformer. The high-tension fuses used on these consist of aluminium fuses in the usual Brown handle. The latter are surrounded on four sides with slate division plates, the front being protected by a removable grating. All the switches and instruments of the 4,000-volt circuit as well as the 16,000-volt circuit are arranged, not on switchboards, but on light, open steel structures, of course everything being well supported on insulators. From the high-tension 'bus-bars of the two banks of transformers are run two sets of conductors (bare) to the distributing board for the overhead line, the front of which is a marble panel arranged on a raised platform on the north side of the room. The latter 'bus-bars are also divided into two sets, which make another ring circuit same as before, or may be separated from each other at different places, so that the separate feeders may be switched on to any of the two services. Each panel contains fuses, an ammeter in each phase, as well as a three-pole oil-break switch. All switches are mounted well above the panels in order to avoid any arc, if any should be formed jumping across from the bars underneath. The switches are all worked by levers, either by means of a chain or rope. From the feeder 'bus-bars wires are led into the open through holes in vertical marble slab, being also insulated by very thick glass tubes. Altogether there are 14 cables led away by the overhead line. Three branch away immediately on leaving the power-house, and are for local consumers in the immediate neighbourhood ; these are at 4,000 volts. The remainder, being ¼ in. diameter, carry current at 16,000 volts, and are carried as far as Thun on iron lattice columns. The insulators are secured in two groups by means of bolts and lock nuts to vertical wooden supports (creosoted), secured to the iron frames at the top of post at a height varying from 28 ft. 6 in. to 39 ft. 6 in.

Three lines are utilised in working the Burgdorf-Thun line. Three go to Burgdorf ; five to Berne, two single-phase and three three-phase. The iron posts, which are fixed in blocks of concrete in the lake itself, are all connected with the earth by a wire passing under the high-tension line. At certain places, especially at curves and railway crossings, the construction is a little heavier. The insulators are of a special type, 6½ in. long, with a double petticoat 4½ in. deep. This line ends at Thun in a distributing tower, and from this point the lines are carried on timber poles from 25 ft. to 46 ft. in height. As said before, five of these lines go to Berne; of the remainder, three go to transformer stations for the railway and the other three to Burgdorf, all supported on poles. In the event of a low-tension wire snapping or springing up against the high-tension lines, all chance of danger is obviated by the fact that the wire would come in contact with the earth-wire first.

The distribution in Berne takes place from a closed-ring circuit formed by the five wires, and surrounds the whole town, to which circuits are tapped on four transformer stations. These sub-stations are arranged in double-storeyed buildings of about 265 square feet area, and consist of a front room, which is utilised as an erecting shop and provided with a travelling crane. The transformer-room adjoins this, and the switch-room is overhead. There are four transformers in each station, although the buildings are designed to take seven, each having a capacity of 50 k.w., and are immersed in oil and water cooled. The leads to the transformers come from the switch-room overhead, along whose walls is arranged all the switching apparatus, high-tension one side, low-tension the other. The switches, fuses, ammeters, and lightning arresters are arranged on identically the same lines as at the central station. The ring circuit can be disconnected from the transformers by means of two special switches arranged close to the spot where the high-tension lines enter the building. These switches are operated by long levers outside the building, so that the portion of the ring circuit situated between two substations may be deprived of the current without necessitating entering the transformer stations and interrupting the working. The pressure is reduced by transformers to 3,000 volts, and the current passes from the secondary 'bus-bars to the underground cables supplying the town. Inside the town the pressure is reduced to 250 volts for driving motors, and to 125 volts for single-phase lighting. At Burgdorf, which is the second distribution centre, the voltage is reduced by two transformer stations from 16,000 volts to 500, and the power is used for driving large motors. For working the smaller motors, as well as for lighting purposes, continuous current is used. This is obtained by two motor-generators which convert 500 volts three-phase to 150 direct current. This energy is distributed by a three-wire system and by two batteries of 840 ampere-hours capacity.

The operation of this installation presents, of course, special difficulties, on account of its being necessary not only to supply a large amount of current for lighting and power purposes only, but also at the same time to provide for extremely large variations in the power required for the railway traffic. In order to prevent these fluctuations from affecting the remainder of the system, the installation is arranged for working two entirely different services. A good idea of the variation may be gained from the fact that it is by no means exceptional for the railway to suddenly take for a more or less considerable period as much as 1,200 H.P. To sum up, the special points to my mind worthy of attention are that the 'bus-bars are arranged exactly as a ring main in a boiler-house. Four of the generators may be switched into one or the other feeder circuits as desired by means of the ordinary switches. The various duplicate 'bus-bars on the generator switchboard in the transformer switch-room, as well as on the feeder switchboards, are all arranged as ring circuits, which, by removing or closing linking devices, can at any moment be divided into any desired section, so that in this way all kinds of combinations in working can be readily effected. The transformers

used are all single-phase, which allow in case of any of them getting out of order to switch in at once a reserve transformer into the corresponding phase. These single-phase transformers enable the output of one phase to be increased by switching in further transformers, which, as in this case, where the whole lighting circuit is connected to one phase, is of special importance for the regularity of the supply. Finally, the whole line is arranged, especially as regards switchboards, with ample room everywhere, so that the extra high pressure does not in any way interfere with the reliability of the system.

Valtellina Line.

A short account of the Lecco-Colico railway may be of interest. I found that although the line was equipped as far as Lecco, starting from Colico, that at that time there was no regular service running, as only experimental cars had been run up to the time of my visit. As is well known, the system is three-phase, with the overhead line at a potential of 3,000 volts. The power is primarily generated at Morbegno at a pressure of 18,000 to 20,000 volts direct. The plant consists of three 2,000-H.P. generators running at 150 revolutions per minute, 15 cycles, having a capacity of 1,300 k.w.; exciters on turbine shaft end; voltage of exciters, 45. The machines are extremely well ventilated and the windings on the machine spaced widely apart.

There are practically two sets of main high-tension 'bus-bars, and each generator feeds into both through high-tension circuit breakers. Each generator has one ammeter, wattmeter, and synchronising voltmeter and lamp; the pressure on the instruments is reduced by static transformers. There are six lightning arresters, three to each set of bars, one arrester being placed in each phase. The high-tension switches are identical with the old Siemens lightning arresters: on opening the contacts the arc forms between the nearest points of the horns and travels upwards, due to the heated air, until it breaks. The current is conveyed from the power-house by means of a transmission line to nine sub-stations situated at the side of the track; at these sub-stations the pressure is reduced to 3,000 volts, which is carried on the overhead line. With one exception only, the sub-stations each contain one three-phase static transformer of 300 k.w. normal rating, but capable of working for a short time up to 900 k.w. One of these nine sub-stations contains two such transformers. The cooling apparatus consists of a small blower driven by an induction motor. The transformer sub-stations are separate stone buildings alongside the railway stations, the transformers being placed in a specially locked room, which is inaccessible to the ordinary railway officials.

The transmission line, at 18,000 volts, runs parallel to the railway a short distance away, but, of course, does not run through the tunnels, of which there are a great number, but over the mountains. Nor does it run through the stations, but at some distance from them. Lightning arresters are placed on the primary line every three miles, and on the secondary every 1¼ miles. The secondary leads are spaced 60 cm. apart, the primary at 87 cm. The secondary is an

ordinary trolley wire, and the primary varies in diameter according to the amount of current it has to carry. A separate span wire is always used for each phase, and double insulated. Of course, the rails are used as a return. All the rails are bonded with ordinary trolley wire, only instead of the pin being solid it is hollow, and collapses when being driven in, and in no case has trouble been experienced through defective contact. Originally the railway company insisted on protected bonds being used, and these were tucked away at the back of the fishplates; but after two years it was found that 10 per cent. of these had got broken, so the plan was abandoned, and the bonds put in an unprotected manner, and just buried in the ballast. Since doing this no further trouble has been experienced. The track is also cross-bonded at about every 300 yards.

On making a trip on the track, I found that the acceleration was extremely even, there being no jolting whatever. The starting resistances on the car consist of water in a tank with fixed plates, the level of the water being raised or lowered by compressed air, which is also used for the Westinghouse brake, the whole apparatus being worked by a small valve in the driver's compartment; the time occupied to take out all the resistance varying from 16 to 60 seconds, depending on the weight of the train, gradient, etc. The air-compressor is driven by a small motor with an automatic switch, which stops the motor when there is sufficient pressure in the tanks. The trains take up to 90 amperes at 3,000 volts to start up, this being the maximum, and from experiments a train on a gradient of 17 in 1,000, with a draw-bar pull of four tons, got up to speed in 37 seconds. There are loop lines on the overhead line through the stations which are made dead as soon as the train comes to a standstill; also the trolley boom is lowered, this being also operated by compressed air, and in the event of a car standing for a long time, there is a small hand-pump to get sufficient air pressure to raise the trolley to get current in order to start up the motor for the air-compressor. The air-compressor also works the whistle.

There are two ways of lighting the trains, either with accumulators or else by means of transformers and lamps with three filaments at 100 volts 15 cycles. A small 8-k.w. transformer supplies current for the lamps, motor, compressor, and heating. The flickering of the lamps was hardly perceptible, more especially those behind ground glass. The same system of lighting was employed at the stations. The main switch on the car was operated also by compressed air, and there was an interlocking arrangement, by means of which it was impossible to get at the switch if the trolley was up, and, of course, impossible to put the trolley up if the switch was open. The trolley was of novel construction, consisting of a copper pipe running on roller bearings, and the whole supported on a wooden shaft. These trolleys have run 30,000 miles without being renewed. The cars are mounted on two four-wheeled bogies, each of which has one primary and one secondary motor mounted direct on the axles. They weigh about 50 tons, and can seat 56 passengers. The locomotive gave a draw-bar pull of 10,000 lb. at 19 miles per hour. The body of the locomotive is

mounted on two four-wheel trucks. Upon each of the four axles a motor is directly mounted, no gearing being used.

All motors are primary, and speed regulation is obtained by using either one, two, three, or all motors to suit the conditions. The rotor shaft, which is hollow, is connected to the car axle by a flexible coupling. The coupling is balanced by counterweights, by this means, although running in fixed bearings can drive the wheel, at the same time allowing the wheel and axle to rise and fall with the inequalities of the road, only $\frac{5}{64}$ths clearance being allowed on the rotor. The average speed is fairly high, as the acceleration is very rapid, although the maximum speed is not excessive, it only being 60 k.m. per hour. They were able to coast above synchronous speed down hill and they coasted below synchronous speed on the flat. The two most efficient speeds were 30 k.m. and 60 k.m. per hour. The whole scheme, including power-house, water power, and canals for same, work out at £4,500 per mile.

On carefully considering the design of the foregoing power-houses and equipment, it seems to me that two things have especially been aimed at—viz., simplicity of design, and a duplicate arrangement of all gear as far as possible. In getting out designs for new power-houses engineers generally consider, in regard to the relative capacity of engines and generators, that the most economical load for the engine shall be that of the maximum load of the generator, and they arrange that, by lengthening the cut-off on the engine, the generators shall be capable of being greatly overloaded without reducing the speed of the engine. In the new power schemes that are before us to-day, where it is absolutely necessary to keep up an uninterrupted supply, it is necessary to take all precautions possible to keep the station 'bus-bars alive at all times and at all costs, notwithstanding any local disturbance which may be taking place outside the control of the power-house. The general source of trouble is fuses, more especially now that much heavier feeders are in use than formerly, so that sometimes when a feeder is shorted it causes an immense amount of trouble by fuses not blowing at the proper time, more especially if the fuses on a system are of different design; also, fuses do not always clear themselves and thus blow the generator fuses, so that endless trouble is caused. By making all the steam plant identical and of sufficiently small capacity, so that in case of a heavy overload it will slow down, all fuses and automatic circuit-breaking devices on the generator panels may be avoided. In the event of a short occurring on a long-distance high-voltage transmission line, the fault would almost immediately clear itself; if not, the engineer in charge will probably notice a different hum in the machines, and will probably have noticed one particular feeder taking an abnormal current, or else that the speed has dropped, and will immediately open the faulty feeder. In case of a continued short-circuit, the lower voltage limits the power which can flow through a fault. By this system any interruption to supply would probably be of very much shorter duration than if fuses are to be replaced and the automatic circuit-breakers closed, after a general opening of all these devices. Of course, there is the risk of all the motor-generators and

rotary converters dropping out of step, but I have known cases where motor-generators have kept in step even with a variation of 20 per cent. in the speed of the generating plant.

Mr. Stewart. Mr. ANDREW STEWART (*communicated*): The first point which caught my eye as I read Mr. Riseley's paper was the amount of plant in the Kander Power-house, some 3,720 k.w. on an area of 4,080 square feet, or 1·1 square foot per kilowatt. This is a figure which, although it has been improved by some of the high-pressure water-power plants employing Pelton wheels on the Pacific coast, is nevertheless a good example of a Continental water-power plant with a medium fall. Having beside me a few figures for power-houses in New York and Berlin, I give them below, with the relative position of the boilers and the type of engines, all of which influence the area required per kilowatt.

Name.	Total K.W.	Area of Ground, Square Feet.	Square Feet per K.W.	Arrangement of Boiler.	Type of Engines.	Size of Unit.	Revs. per Minute
Metropolitan, N.Y.	38,500	48,800	1·26	On 3 floors	Vertical Cross Compound	4,500 h.p.	75
Kingsbridge, N.Y.	78,830	56,000	1·4	On 2 floors	Vertical Cross Compound	4,500 ,,	75
Manhattan, N.Y....	82,416	40,000	2·05	On 2 floors	Duplex Compound	8,000 ,,	75
Oberspree, Berlin	43,000	280,000	6·5	On 1 floor	Horizontal triple Gorlitz	1,000 ,, 2,000 ,, 3,500 ,,	83
Moabit, Berlin ...	33,000	363,000	11·0	On 1 floor	Horizontal triple Sulzer	3,500 ,,	83

Mr. Stewart.

Oberspee and Moabit will have all extension units of 6,000 H.P., and figures given are based on ultimate capacity of station when buildings are full.

The German H.P. is 1½ per cent. smaller than the English, but that does not materially alter the figures. On my visit to the Berlin stations some months ago neither had reached its full capacity, but there was no evidence in either case of economical tendencies as to ground space, chiefly because ground was very cheap, each station being located some miles from the centre of the city. The figures probably represent the extremes of large power-station design, as even in London the area per kilowatt of any of the stations is not much less than that of the Metropolitan Station, New York, although in conversation with the engineer of one of the new underground railways for London I learned that with Parsons turbine units it was hoped to get the ground space in one power-station down to one square foot for each kilowatt installed.

Mr. Riseley's reference to the transformation of three-phase currents by three single-phase transformers is also interesting, instead of the more usual Continental plan of employing three-core transformers for this purpose. The ease with which another single-phase transformer may be switched in to replace any one of the three should it happen to break down, is not sufficient to justify the extra capital expenditure, which may be 10 to 20 per cent., depending upon the size. In addition to this, I note that a good proportion of the power at Berne is used as single-phase, where of course there will be some tendency towards unbalancing. This tendency can best be checked, if not quite suppressed, by the use of three-core transformers, the interaction of the three phases being sufficient for this purpose. If Mr. Riseley has heard this point raised at Berne, perhaps he can throw some light on it.

Another interesting point is the Lecco-Colico line, where it appears that 15-cycle 3-phase currents are employed throughout. It would be interesting to know what considerations led to the choice of this low periodicity; certainly the motors and transforming apparatus would cost a good deal more than with a higher periodicity. One consideration which appears to justify this low periodicity would be the greater apparent resistance of the rails with currents of a higher periodicity. If the rails have a large section, this would probably become a matter of considerable importance, but it is doubtful if it was the reason for the adoption of a periodicity of 15 cycles. Perhaps it may have been due to mounting the motors direct on the axles, and using driving-wheels of small diameter; this, with a small number of stator poles, say four, would correspond to the higher speed mentioned by Mr. Riseley, viz., 60 kilometres per hour, but this would involve wheels approximately 30 inches diameter, and it is improbable that the motors could be mounted directly on the axle in the space available. There must of course be some good reason for such a departure from recognised practice. Another point is the statement that each bogie on the cars has two motors, one primary and one secondary; this would lead one to suppose that they are arranged permanently in cascade, which seems unlikely, unless when running at 30 kilometres per hour, while the next paragraph says "all motors are primary." It is difficult to reconcile

Mr. Stewart. these two statements, as they indicate directly opposite practice, and I should like to have Mr. Riseley's views.

Mr. Woodhouse. Mr. W. B. WOODHOUSE was interested in comparing the methods adopted for the protection of the system in the stations described with those used in other countries. He noted that the use of fuses was general, but he was surprised to find aluminium fuses still in use. Aluminium had been used because its specific heat was large, and it was possible, by carefully proportioning the cooling surface, to make such a fuse act as a time-limit cut-out, but the difficulty of making a good connection had caused most engineers to abandon its use in favour of tin, to which copper connecting strips were sweated. Modern practice in this country and in America was to abandon fuses altogether in favour of automatic oil-break switches; feeders were protected by overload time-limit switches at the generating end, and overload and non-return power switches at the receiving end. He did not consider automatic switches or fuses necessary on generators, an oil-break switch being sufficient, if properly enclosed in an iron box; he quoted a case of such a switch repeatedly breaking 12,000 kw. at 45,000 volts without damage. With regard to a suggestion of Mr. Riseley's, that small engines should be used which would pull up on a short-circuit, the speaker could not agree with this rather primitive method, as all the synchronous sub-station machinery would undoubtedly fall out of step. An automatic switch was the proper thing to use.

Mr. Stoney. Mr. G. G. STONEY said he was much indebted to Mr. Riseley for his paper. It enabled us to compare our systems with those of our Continental competitors.

When he was over in Germany the thing which struck him most was that the capital expenditure was excessive, especially for buildings. Take two modern stations. The style of buildings would never be countenanced in this country, and the space occupied by the plant was excessive. It was 1½ square feet per kilowatt, without taking into account switch-room. If the switch-room were taken into consideration it would work out at 1¾ square feet. The space used was 1⅛ at Neptune Bank. In one station £130 per year was spent on washing floors. The result of this excessive expenditure would be disastrous at some future time. The charge for current was higher than it was in England, being as high as 7d. and 8d., whilst in Newcastle it was 4½d.

His opinion was that for real sound work England was far ahead of the Continent. He quite agreed with Mr. Woodhouse that fuses were a great nuisance. He would be inclined to do away with fuses, especially main fuses, on machines. Fuses of aluminium in china handles, of the Brown-Boveri type, seemed to work fairly well.

Mr. Vesey Brown. Mr. C. S. VESEY BROWN said that one envied the French, Swiss, and Italians in the possession of their magnificent waterfalls, and unfortunately the conditions in England were so different that manufacturers and others connected with central stations were obliged to use steam to compete with their Continental neighbours. He did not know of any other water-power station than that of Reinfelden, in Germany, where most of the stations were steam-driven.

Mr. Vesey Brown.

In reference to the author's remarks on fuses, he had found that the general rule on the Continent was to use pure silver, which was far more reliable and certain to go at the proper current density. For his part he had given up the use of fuses for large currents except where it was required to disconnect any leads, and preferred to use instead a good maximum automatic cut-out with a carbon break attached.

At his first visit to the Cologne Station in 1891 he found that the authorities were most particular as regards periodicity and pressure, and, in fact, were so successful as to be able to run about two dozen clocks in synchronism with the generating plant, and these clocks were set once a week.

There were many opinions as to the question of using storage batteries, and they had certainly stood the test of time at Dresden and Dusseldorf, but the tendency being all in favour of three-phase generation had to a certain extent displaced the storage battery. There was certainly the point as to constancy of pressure which was more particularly brought to the front when Nernst lamps were used on the circuits, and in his opinion the use of the Nernst lamp required that the pressure should not vary beyond the very narrowest limits from the standard pressure. It seemed a pity that in the town in which they were at the present moment, that the use of the Nernst lamp had to a very great extent been killed by the great variations in pressure to which the distributing system was subjected, and he thought that this might be remedied by the use of storage batteries.

On the Continent the price of supply was as a rule higher than in this country, but this was due to the very lavish manner in which the buildings had been laid out, and as the upkeep was heavy, so the consumer had to pay more for his supply. The Continental proprietors were satisfied with a slightly smaller return on the capital put into the stations, for as a rule, where the stations were not owned by the local authority, they were owned by manufacturing companies, who put a good price on the value of their plant at the commencement. In some cases the tax to be paid by the concessionaire to the local authority before the shareholders received anything was 6 per cent. on the capital employed; in others it was as high as 1d. per unit.

Referring again to the use of storage batteries to steady the pressure, he was informed at Essen that the town authorities imposed a fine for irregularity of pressure and failure to supply, but that up to the present no fines had been imposed in consequence of any failures, etc.

In his opinion the German stations were much better finished than the French and were generally cleaner, though they were both a great deal ahead of this country in this respect.

Mr. Turnbull.

Mr. C. TURNBULL said he was interested in Mr. Riseley's remarks on cellular switchboards. People were often led to believe that the only fault of this type of board was its high cost, although the board certainly appeared rather inaccessible. He was pleased to hear the criticism of one who had used them.

With regard to running dynamos without fuses, it was to be observed that an engine's power went off rapidly as soon as it slowed down, and he believed it well worth while—speaking from experience—to have

Mr. Turnbull. dynamos large enough to pull the engine up without damage to the dynamo.

Mr. Snell. Mr. J. F. C. SNELL said he would like Mr. Riseley to tell them whether he found the oil-break switch more in use than the air-break switch. He understood that the Continental practice was to use the horn-switch. He was, however, sufficiently English to have adopted oil switches in connection with his three-phase plant.

It occurred to him that the money spent on buildings—particularly on the engine rooms—on the Continent was very excessive indeed, owing to the fact that they used slow-speed engines which covered a great deal of room. This was, of course, done with an object, the cost of coal being so great that they were obliged to adopt every possible means in their power to reduce the consumption per unit sold. The sub-stations of Berlin struck him particularly as being lavish. The walls in some cases were 36 inches in thickness, and the floors were most heavily made with glazed brick facings. Although land was dear, the fact of putting accumulators on the first floor when they could have been put in the basement seemed waste of money. While he thought that their engine rooms looked better, their boiler-house equipment was wanting when compared with English practice. English central station engineers would be ashamed of the usual Continental boiler house. The arrangement of piping also seemed to be bad. Supposing they had a superheat of 250° at the boilers a good deal must be wasted before reaching the engines, owing to the long pipes employed.

It was interesting to hear the remarks about the single-phase transformers. He found three-core much cheaper than three single-phase to install. None of the previous speakers touched on the question of railways. The Institution had wisely arranged a trip to Italy this year. He hoped the experiments on railway equipment being made in Italy would teach us a great deal and have the effect of awakening our English engineers.

Mr. Clothier Mr. H. W. CLOTHIER said he was not so favourably impressed with the design of Continental switchboards as Mr. Riseley. When he visited stations containing such switchboards he found that the backs were not open for inspection to visitors, and he instanced one place where he learnt that two men had been electrocuted behind the board. He alluded to the comments on British switch-gears, and thought that an unfair comparison had been made. The cellular switch-gears at present in use in this country were designed for pressures of about 5,000 volts and under, whereas the Continental system taken as an ideal was working at 13,500 volts; when the demand for higher pressures arose in this country we should produce designs to excel those seen hitherto by the author. He did not attribute so much importance to the duplication of 'bus-bars which introduced complication and chances of error. He drew attention to an error in one of the diagrams which was a good example of the difficulties due to too much complication; if the draughtsman could so easily err, what was to be expected of the operator?

Mr. Riseley had said that on the boards to be seen on the Continent,

such as that at Paderno, there was "always another way round, *everything* being in *duplicate*, but he (Mr. Clothier) thought that an examination of the diagrams would show that such was not exactly the case. The 'bus-bars were in duplicate, but that was all. He maintained that apart from the complications involved (which were common to any type) there was no difficulty in obtaining by this means "another way round" on the British cellular gear; as a matter of fact he could mention many cases in this country where duplicate and even triplicate 'bus-bars were in use. Mr. Clothier.

He said that flare switches for alternating-current systems were fast dying out, because of the high voltage oscillation set up by the arc. In the light of our experience and the expert opinions of this country and in America, no one would think of installing switches of the same type as those in use on the Valtellina line.

He was entirely in accord with the author in his practical opinion as to dispensing with fuses on the generator circuits, fuses there were more often than not a huisance; they were wanted on the feeders, and he thought reverse current indicators on each machine circuit were used to advantage.

Speaking of the general design of British switch-gears, he admitted that there was ostensibly much to be done before they could be considered perfect for extra high voltages; but in arriving at finality in design, if that were possible, we should take into account the enviable record of no fatal accidents on the Ferranti cellular switch-gear during all the years it had been extensively used on high-tension supply systems.

Mr. J. H. Holmes said he had the pleasure of visiting Kander Power Station with some members of the Institution. Mr. Holmes.

The thing that struck him most was the great difficulty they had in regulating and governing their turbines. It seemed impossible to design an automatic governor which would be of any use. When he was there he had noticed the man at the hand-wheel, and he was interested to learn that he was still at it.

Mr. H. L. Riseley, in reply, said that Mr. Stewart's figures of area of ground per kilowatt installed were very interesting, and he was sorry he could not add to the list. The sole idea of using single-phase transformers was, he was informed, for the convenience of changing over in case a transformer got damaged. *Valtellina Line.*—He presumed that the reason of choosing a periodicity of 15 cycles per second was the wish to mount the motors direct on the axles. The wheels, instead of being 30 inches, were 3·84 feet in diameter on the motor cars, whereas on the locos. they were 55 inches in diameter. The motors were mounted directly on the axles in a very interesting manner. The gear consisted of a very neat parallel-link connection between the driving hollow rotor shaft and the wheels. Each pair of wheels was keyed to the shaft, of which the diameter was 4½ inches less than the inside bore of the hollow shaft, and the link gear compelled the two to rotate accurately together while giving complete freedom to the wheel-shaft to rise and fall with the axle boxes between the horn plates without any vertical motion of the rotor, stator or motor as a whole. Mr. Riseley.

Mr. Riseley The whole weight of the motor was borne on springs; the bearings of the rotor shaft were fixed in the casing of the stator. The wheel was driven by pure torque, that is to say, by two equal and opposite forces producing no reactive resultant pressure in the bearings in which the rotor ran. The whole load, including the weight of the motor, was carried at the axle box.

As regards the primary and secondary motors, each motor car was fitted with two primary and two secondary motors, but on the locos. all four motors were primary, and speed regulation was obtained by using either one, two, or three, or all motors, to suit conditions. On the bogie cars each truck carried two motors, one on each axle. These were used in cascade up to half-speed, and also in slowing down from full-speed to half-speed. In accelerating from half- to full-speed, and in running at full-speed, one of each of the pair of motors was cut out and was running idle. Of course, in cascade-working during the first period of acceleration, the resistance was placed in the rotor circuit of the secondary motor, in the stator of which the voltage did not rise above 300, this being derived from the rotor of the primary motor, which current was drawn off slip-rings. The Controller had only three positions: (1) half-speed; (2) mid position, when the resistance was cut out and the primary rotor circuit was open, and (3) full-speed, for acceleration from half-speed to full-speed.

Mr. Woodhouse mentioned aluminium fuses and seemed to have the idea of making fuse contacts of aluminium strip. Messrs. Parsons & Co. used special blocks for soldering aluminium strip.

As regards the time-limit circuit-breaker he did not see any in operation, though he understood that they were experimenting in Newcastle with them and that they were working fairly satisfactorily.

Regarding the last paragraph of the paper his idea was, supposing you get a number of 100 k.w. generators running in parallel with identical engines of the same rated power. In that case, should any overload occur, all the engines would slow down together, instead of a more powerful engine trying to take all the load and thus upsetting the parallel running of the station. He only offered this as a suggestion.

In reference to Mr. Stoney's remarks, no doubt some of the Continental stations were got up most expensively, especially that of the Schuckert Corporation Station at Vienna. The work of cleaning the station was a big item; in some cases it cost £2 per week to keep the floor clean. He did not remember seeing a station in England kept so clean as the Continental stations.

In regard to the point raised by Mr. Vesey Brown about the cheapness of water-power abroad, the capital expenditure incurred in applying water-power was enormous. In some cases they were using steam plant, as the capital outlay in utilising the water was almost prohibitive, and they found it better to have steam engines.

With reference to sub-stations being well equipped, he did not know that it did not pay to put in all the automatic devices you can. It certainly saved labour.

Turning to Mr. Clothier's remarks: he did not think there was anything in the paper about Ferranti switchboards. There was more than

Mr. Riseley

one type of switchboard called multicellular. There certainly were several points on the Ferranti switchboard which could be improved. Accidents with it were not unknown. It certainly was an advantage to be able to get behind the board, which it was impossible to do with the Ferranti board. He agreed with Mr. Holmes that the governing at Kander was extremely bad. With a large volume of water rushing down under a high pressure, it was evident that the governing could not be very uniform.

BIRMINGHAM LOCAL SECTION.

NETWORK TESTS, AND STATION EARTHING.

By A. M. TAYLOR, Member.

(*Paper read before the Section, February* 25, 1903.)

The object of the present paper is, primarily, to describe a new station test, for application under working conditions and on systems where the middle wire is permanently earthed; but as the utility of the said tests—or, indeed, any known test—depends considerably upon the method of earthing adopted, it has seemed desirable to add a few notes on this subject also.

SECTION I.

DESCRIPTIVE OF TEST, AND EXPLANATORY DIAGRAM.

Referring to the simple diagram of circuits, Fig. 3, let E represent part of the earth circuit, and P, M, N the positive, middle, and negative leaks respectively.

D, D are the dynamos or steam balancers at the station. AA is the Board of Trade Recording Ammeter, reading from 0 to 100 amperes, the neutral being earthed through a resistance of 2·3 ohms, as shown.

For the present, consider only the currents P, M, N, and let the leak P be of lower resistance than N, so that the potential of the earth tends towards that of the positive pole.

Consider also, for the moment, that the resistance of the earth is negligible, and hence that the earth potentials at the leak and at the station are the same.

We can represent this state of things by the small diagram on the right-hand top corner of Fig. 1.

Fig. 1 represents, to scale, the changes which take place in the values of N, M, P; and AA, if we can imagine the potential of the earth pulled, by some external means, through every value from extreme positive to extreme negative.

To enable this diagram to be better understood, the author has dissected that part of it which relates to the P and N leaks; and the two triangles, the ordinates of which represent at any moment the actual values of the currents P and N, are shown separately in Fig. 2 (consider only the full lines). The dotted lines of Fig. 2 are intended to help to the better understanding of Fig. 14 (see Appendix, Note 1).

The differential leak is given us by the ordinates drawn between the base line and the line AB, Fig. 1, which for shortness we will call the P–N line: see also Fig. 2. The point at which this line crosses the hori-

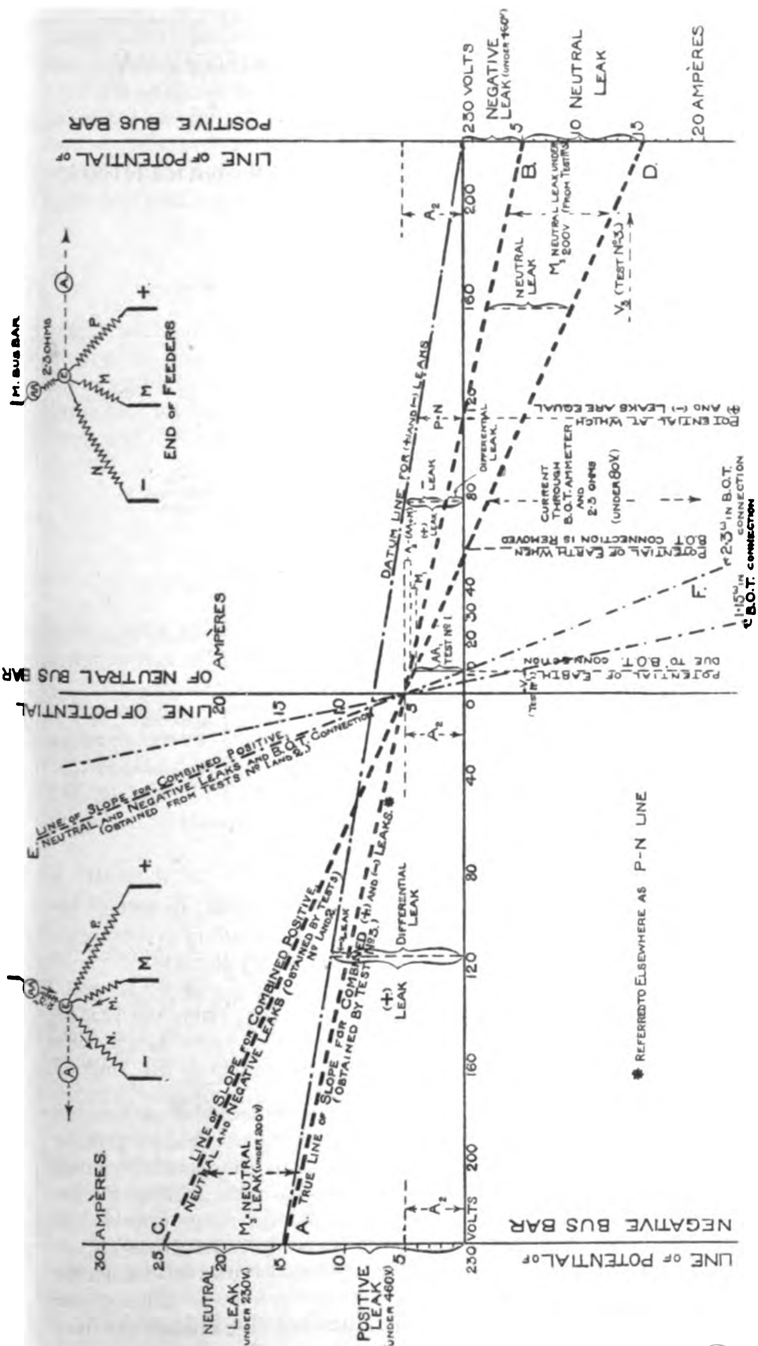


FIG. 1.

In this diagram, Tests Nos. 1 and 2 refer to the "Combined Leak Test," and Test No. 3 refers to the Neutral Leak Test.

zontal gives us the potential of the earth when $P = N$, there being assumed to be *no* neutral leak.

Next, introduce a neutral leak, indicated by the lengths of the ordinates between AB and CD, and we see the effect in bringing the earth potential nearer to that of the neutral 'bus-bar. The point of crossing of CD with the base line is now at 60 volts.

Again, add a further line EF, representing by the ordinates between it and the line CD the current in the B.O.T. connection (made through

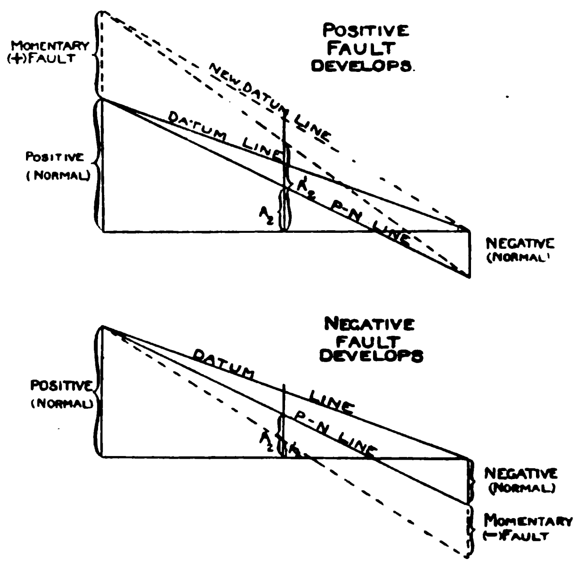


FIG. 2.

2·3 ohms), and we have the new potential of earth, viz., 10 volts, where EF crosses the base line. The ordinary B.O.T. reading is represented by the ordinate AA_1 at V_1 volts, where $V_1/AA_1 = 2{\cdot}3$ ohms.

It will be obvious that no end of combinations of P, M, and N will give the same B.O.T. reading AA_1. Also that from the readings AA_1 and V_1 (or from V_1 alone) we could, if only we knew A_2, the differential leak when $V = O$, deduce the slopes of the lines EF and CD. The slope of the latter line gives us the *combined* insulation resistance of the three mains; which is :—

$$F = \cot. a = \frac{V_1}{A_2 - \dfrac{V_1}{2{\cdot}3}};$$

where a is the angle which CD makes with the horizontal.

To find the *individual* values of the leaks we must somehow separate out the neutral leak from the others. Obviously, if we could only insert an ammeter in the neutral leak and measure the little ordinate M_1

under V_1 volts, we could deduce the slope of the P–N line; but, unfortunately, this is impracticable, and would be only an approximation in any case, as M_1 is so small.

Referring, however, to Fig. 3, we see that by means of an artificial fault at the station we might put M under any voltage we choose, and measure the increase or diminution of the current supplied from the station to the leak along the neutral feeders. Knowing the current

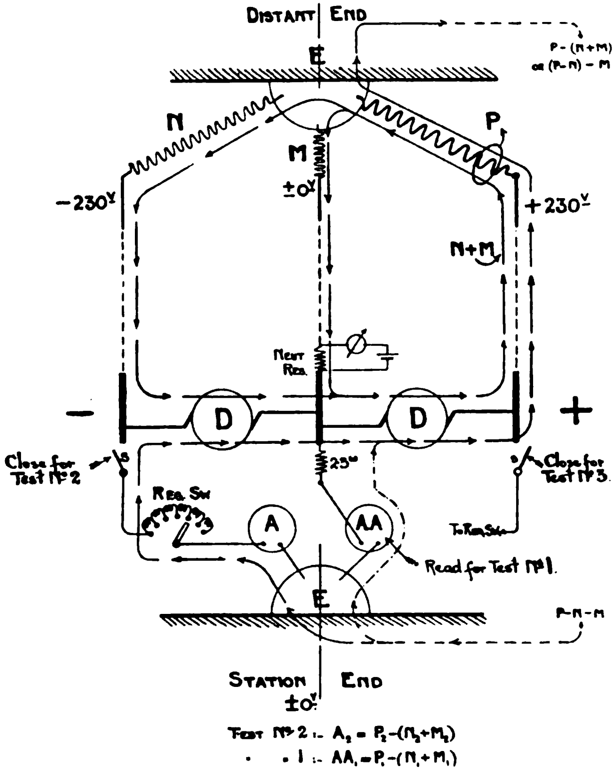


FIG. 3.

produced under V_3 volts, it is sufficiently correct to assume that under V_1 volts we should have V_1/V_3 of the current.

The author has successfully measured the increase or decrease of the neutral current by interposing between the neutral 'bus-bar and the neutral feeders a resistance, consisting of iron plates bolted together, constructed to absorb about a couple of volts, and balancing against this an accumulator cell with an ammeter in its circuit arranged to read zero when the normal out-of-balance current of the station traverses the resistance.

The difference in the reading when the neutral leak is under no

E.M.F. and when it is under V_3 volts enables us to ascertain the current through the neutral leak under V_3 volts, whence we know M_1.

It remains to explain how the reading A_2 is obtained. A reference to Fig. 3 will show how it is picked up by the ammeter A at the station through the switch and adjustable resistance. When $V = O$, then $M = O$, and $A_2 = P–N$.

Where the values of V_1 and A_2 are both so small as to introduce inaccuracy, it may be found desirable to take a reading A_4 at V_4 volts—say 10 volts—to the left of zero (Fig. 1), in addition to the reading A_2 at zero voltage. Then—

$$F = \cot. a \frac{V_4}{A_4 - A_2 - \frac{V_4}{2 \cdot 3}}$$

Fig. 4 shows the testing panel, as arranged by the author. The switch shown at the top, when thrown over to the right-hand side, introduces a central-zero ammeter AA into the B.O.T. circuit, which gives us the normal B.O.T. ammeter reading AA_1 under the voltage V_1 measured on the central-zero voltmeter shown.

The ammeter is unnecessary, since AA_1 can be calculated from V_1, but it saves reference to a table.

The second ammeter A is controlled by the two lower switches, the upper of which puts the free end of the ammeter circuit on to either "outer" 'bus-bar (through a fuse), and the lower on to the neutral 'bus-bar. The other end of the ammeter circuit, which contains an adjustable resistance, is in permanent connection with earth. The circuits are fused for 100 amperes.

To take the reading A_2, all that is necessary is to close the upper of the two lower switches on to the 'bus-bar remote from that towards which the voltmeter reads and adjust the resistance slider till $V = O$. Then on the ammeter A we observe the reading A_2.

To measure the neutral leak, close the top switch on to the left-hand side, thus putting the ammeter AA into the battery local circuit (see Fig. 3), read the ammeter AA, the earth being at about the potential of the middle 'bus-bar, take any suitable proportion of the resistance out of the slider, and close the upper of the two lower switches on to either "outer" stop. The increase or decrease in the reading of the ammeter AA multiplied by a simple ratio—in the case the author has used the ratio is 5/4—gives the neutral leak M_3, and the voltmeter measures the volts V_3 under which it is produced.

For localising a fault to any particular feeder, a 20-way slider is arranged with an ammeter in such a way that the link connecting any one of the neutral feeders to the distributing bar on the neutral feeder panel can be opened, and the ammeter switched into its place.

If the last test be now repeated, the feeder on which the neutral fault exists will give a very pronounced deflection amounting to perhaps 50 or 100 amperes if the fault is a bad one.

Suppose, now, that instead of a neutral fault we had a positive or negative one. Then our test would have shown the neutral 'bus-bar to be sound, and by the slope of our P–N line we should have

known to which side to have looked for the fault. The next step would be to cut some or all the resistance out of the slider, and to close the upper of the two lower switches on to the right-hand stop (for a negative fault), having previously graded the fuse for, say, 100 amperes.

On inspecting the feeder ammeters on the faulty pole, the faulty feeder will be at once seen.

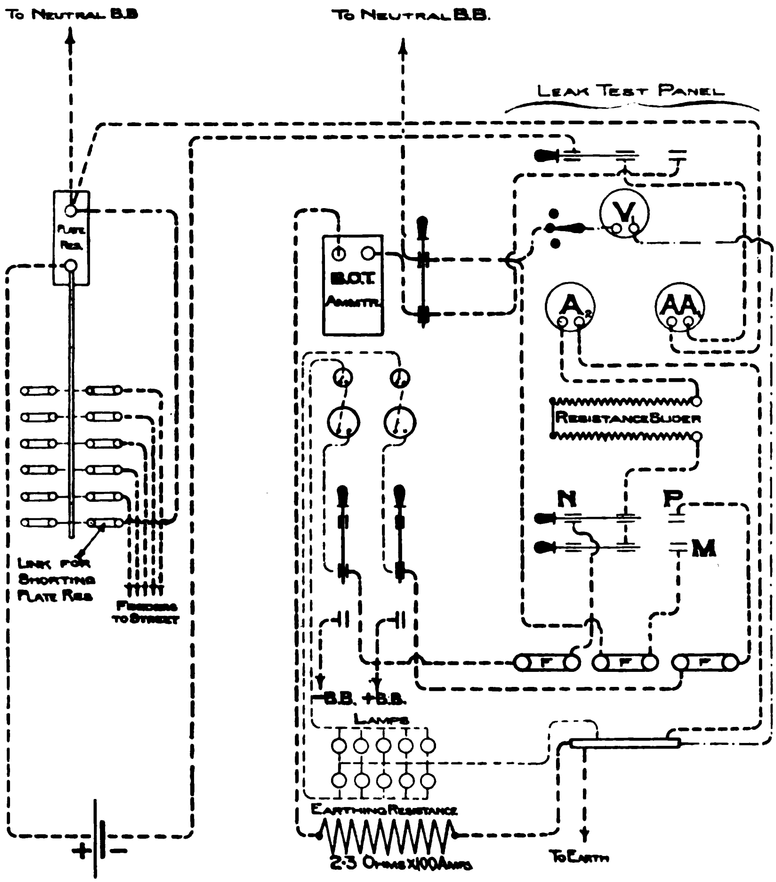


FIG. 4.

SECTION II.

REASONS FOR A NEW TEST.

The B.O.T. Recording Ammeter, for the reasons already given under Section I., is not, as is well known, of any assistance in gauging the standard of insulation of our mains; though it is, no doubt, of

considerable value as a recorder of any *change* in the state of the insulation (except perhaps in that of the neutral) from day to day. Hence some means of keeping the mains up to a standard is necessary.

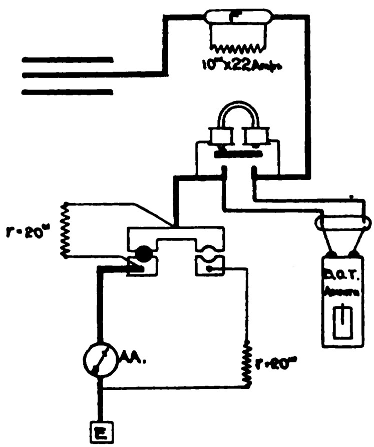
The four tests available were:—(*a*) Fritch's Test; (*b*) Frolich's Test; (*c*) A modification of Frolich's test by, and apparently due to, Mr. F. C. Raphael; (*d*) Mr. Alex. Russell's test.

The first three are described in Mr. Raphael's book on "Faults in E. L. Mains," and they need not therefore be described here. Mr. Russell's test (*d*) is described in the Journal of the Institution, Vol. 30, No. 148.

With reference to these tests, the author would make the following remarks:—

(*a*) Frisch's test is unavailable where the neutral is permanently earthed, through a low resistance or otherwise.

(*b*) Frolich's test is also ruled out of court, because the resistance of the ammeter circuit must be great in comparison with the insulation



COMBINED AMMETER AND EARTHING CONNECTION
RAPHAEL'S TEST C

FIG. 5.

resistance of the network to be measured; that is to say, if we are testing a network in a station supplying, perhaps, 50,000 60-watt lamps, the joint insulation resistance of whose mains might measure, say 20 ohms, we should need to insert an ammeter having in its circuit a resistance of, perhaps, 200 ohms, between the neutral and the earth, instead of the connection required by the Board of Trade.

(*c*) The modification of Frolich's test described by Mr. Raphael, though no doubt more practicable than the others, still seemed to be somewhat unsatisfactory.

In this test the neutral is temporarily connected to earth through an

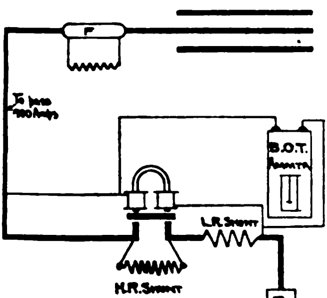
ammeter in series with a resistance about equal to that of the insulation resistance of the network, and this circuit is then shunted by another resistance of equal value.

The resistance to be inserted during the first half of the test would then be, for the case above cited, about 20 ohms.

In the case, however, of a small system, the resistance to be inserted might amount to as much as 50 or even 100 ohms; which would be practically a disconnection from earth.

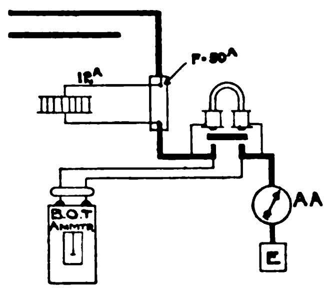
There would seem to be some danger of the two resistances being burnt out, in the event of a bad earth on either "outer" occurring while the test was being made, the connections being as in Fig. 5.

Apart, however, from all questions of safety—for of course the resistances could be constructed to jointly carry 25 amperes under 250



A.T. Abrahams Arrangement

Fig. 6.



Glasgow Arrangement.

Fig. 7.

volts—the reason why this test appeared to the author to be somewhat unsatisfactory was that it only measured the *combined* insulation resistance of the three mains, and not their *individual* resistances.

(*d*) The same objection applied to the test (*d*); with the additional disadvantage that it involved the entire interruption of the B.O.T. connection with earth at the time of making the test.

Now, given that the insulation of the system has gradually fallen below the standard—but with no pronounced leak on either pole—the mere measurement of the joint insulation resistance of the three mains as obtained from test (*c*) does not help us as to which pole we are to look (positive, negative or neutral) for the low state of insulation.

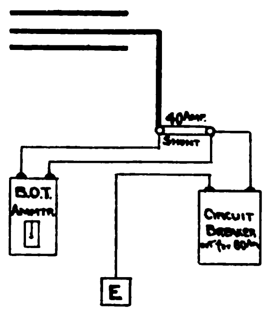
And for the reasons given under Section I. the B.O.T. Ammeter is just as likely to mislead us, as to help us, in looking for the faulty pole; its operation being under similar conditions to those of Raphael's test (*c*).

Suppose, for example, that we had 60 feeders, in all, issuing from the station, viz., 20 positives, 20 neutrals, and 20 negatives, it will

clearly save us a possible 40 unnecessary tests if, to begin with, we know whether the fault is on the positive, negative, or neutral main.

A test panel, to be useful, should therefore fulfil the following functions :—

(1) It must indicate on which pole the leak is developing.
(2) It must enable us to ascertain on which of the feeders (connected to that pole) the fault exists.
(3) It should enable us "to clear"—or, failing this, to localise—the fault by a momentary application thereto of increased pressure; and yet to limit in amount the current which might otherwise be put through the fault.
(4) It should not interfere with the existing B.O.T. connection to earth.



MANCHESTER ARRANGEMENT

FIG. 8.

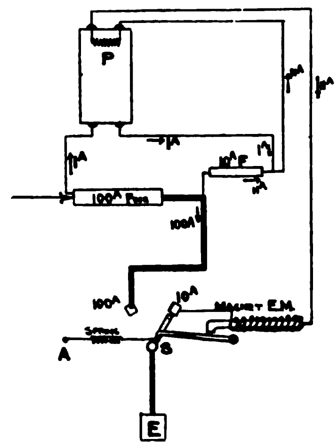


FIG. 9.

The coil P holds the auxiliary 100 amps. pen off paper. A rush of current through the magnets E M and P liberates switch S and auxiliary pen simultaneously. The 10A shunt is shorted by the 100A shunt when switch flies over.

The panel designed by the author, and described earlier in this paper, is intended as an attempt to fulfil the above conditions.

The method of operating the panel is explained under Section I. of the paper.

A further reason for a test which will give us the P and N leaks separately—*i.e.*, the slope of the line AB—is that the B.O.T. Regulations require that, in public supply, the leakage current shall be less than one thousandth part of the supply current.

Now, the supply current is measured by the sum of the positive and negative 'bus-bar outputs; hence the leakage current must be measured in the same way; viz., by the *sum* of P and N. The insulation of the

neutral may be quite low; but the actual leak M through it is, under normal conditions, quite negligible.

Hence, if we obtain the joint insulation resistance of all three mains by any of the tests mentioned, and divide this into 230 volts (to get the actual leak), we shall be misled into thinking that the insulation is below the B.O.T. standard when it is really above it; *nor have we any means of gauging* by how far the state of our mains really comes short of, or exceeds, the B.O.T. requirements.

Most station engineers would like to be assured on this point, and all want *some* standard to work to.

SECTION III.

Relative Efficiency of Different Methods of Earthing.

In considering this subject the two principal things to keep before us are continuity of supply and safety to the consumer. The contingencies that we have to face, as likely to happen outside the station, are :—

(1) Earths on the neutral on consumer's premises.
(2) Earths on either "outer" on ditto.
(3) " " " on the system of mains.
(4) Various combinations of these.

In each case the effect of permanently earthing through a moderate resistance—say 2·3 ohms—will be compared with the effect of a *direct* earth connection, whether made through a fuse of large capacity or otherwise. See Figs. 5, 6, 7, 8, 9.

In Fig. 10 is shown the case of a consumer A whose neutral makes

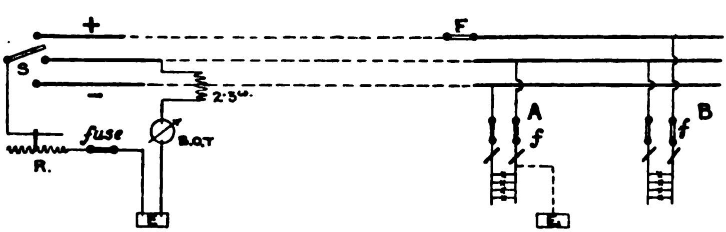


Fig. 10.

an earth connection E somewhere. Here we see that the *partial* earth at the station reduces the risk of a portion of the return current from installations B, C, D, etc., being shunted out of the neutral distributor through A's premises and the fault on his installation, and so blowing the fuse *f* and leaving A cut off from supply—except through the fault—just as the evening load comes on.

In Fig. 11 A's installation is sound, but B has a fault E on his

positive side. In this case the *partial* earth at the station somewhat reduces the chance of B having his fuse *f* blown, and being unable to get a light when he switches on in the evening.

A further advantage of the partial earth is that in case B's installation should be a large one, and its fuse graded too heavy, the distributor

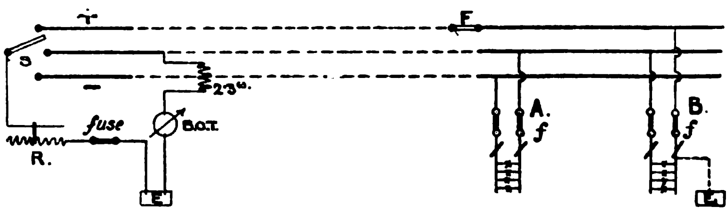


FIG. 11.

fuse F might be saved from being also blown and all consumers on that section being put in the same case as B.

It will also be evident that, by means of the author's test panel, the station engineer can, at any moment, cut out the resistance R at the station and close his switch S; thus blowing B's fuse and locating the fault to a particular feeder.

Also it will be seen that, by means of the fuse on the test panel, the current could be graded and, if found to be so large as to mean the extinction of a number of lights, the blowing of the consumer's fuse *f* could be deferred, at the discretion of the engineer, till daylight.

In Fig. 12 all consumer's installations are sound, but there is a fault

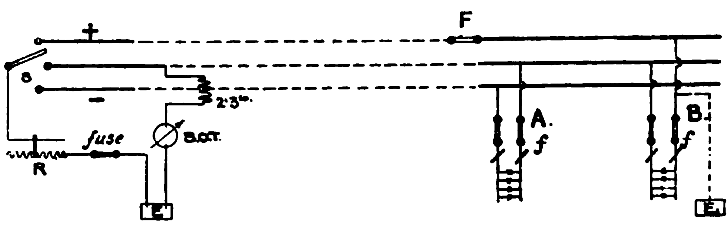


FIG. 12.

E on the service connections or on one of the "outers" of the distributing system.

In this case it is clearly an advantage to have only a partial earth at the station; for if the station "neutral" were earthed *direct*, or through a heavy fuse, there is considerable risk of blowing the distributor fuse F and putting the whole of the consumers on that section in darkness; this, too, for a fault, not on the consumers' premises, but on the mains.

Stating briefly the arguments for, and against, earthing through a resistance in these several cases, we have :—

FIG. 10 :—

(1) Reduced risk of A being cut off from station just as darkness comes on.

FIG. 11 :—

(1) Reduced risk of all consumers on the section being cut off from supply through fault on B's installation.
(2) Reduced risk of B's installation being cut off from supply unnecessarily.
(3) Equal facility for locating from station.

FIG. 12 :—

(1) Reduced risk of plunging all consumers on the section into darkness, through fault on mains alone.
(2) Equal facility for locating from station.

FIGS. 10 and 12 (combination of) :—

(1) Reduced risk of plunging all consumers on the section into darkness.
(2) *Increased* risk of A's lamps being burnt out, through his fuse *f* blowing.
(3) Equal facility for locating from the station.

FIG. 10 and 11 (combination of) :—

(1) Reduced risk of all consumers on the section being cut off from the supply.
(2) Reduced risk of cutting off B from the supply.
(3) *Increased* risk of A's lamps being burnt out (through fault on his own premises).
(4) Equal facility for localising both A and B from the station.

FIGS. 11 and 12 (combination of) :—

(1) Reduced risk of all consumers on the section being put in darkness or cut off from the supply.
(2) Reduced risk of faulty consumer being put in darkness.
(3) Equal facility for localising from station.

FIGS. 10, 11, 12 (combination of) :—

(1) Reduced risk of all consumers on the section being put in darkness or cut off from supply.
(2) Reduced risk of cutting off B from supply.
(3) *Increased* risk of burning up A's lamps.
(4) Equal means of localising A and B and faulty distributor.

Summary of "Pros" and "Cons."

FIGS. 10, 11, 12.—These are the *most likely* cases, requiring the fewest combinations of accidents; and *in every one* of these the conditions are favourable to inserting a resistance permanently at the station between the neutral and earth.

FIGS. 10/12, 10/11, 10/11/12.—These are, in the main, favourable to the change. The faulty consumer is the only sufferer, which is but right.

FIG. 11/12.—This case, again, is all in favour of the change.

There seems, therefore, a distinct preponderance of argument in favour of inserting the resistance.

The above conclusions do not consider the possibility of the fuse, which makes the "dead earth" connection, melting.

It may be argued in favour of having a fuse that, by employing a light fuse to shunt the earthing resistance at the station, the consumer's fuse is saved from blowing (see Figs. 10 and 11), in the case of a light fault.

The answer to this is that, in Fig. 10, the current would not have attained to the dimensions indicated by the blowing of the station fuse had this fuse not *facilitated* its flow by being placed to shunt the resistance; while, in Fig. 11, the fuse might as well have been absent, for it cannot be replaced till the consumer's fuse has blown; and, if the latter do not blow with the former, then *neither would it have blown* had there been *no* fuse, but only the resistance. In the case of a "dead earth" fault the consumer's fuse is sure to go, anyway.

If, on the other hand, we employ a *heavy* fuse at the station to shunt the resistance we shall have, in the case of a bad fault on consumer's premises (Fig. 11), both current *and* pressure available at the fault, or at the consumer's fuse, sufficient to maintain an arc, or do other damage, many times greater than if there had been no station fuse at all.

Further, the fuse involves us in automatic devices, and in two scales, for the B.O.T. Recording Ammeter.

All seems to point, therefore, in favour of having a resistance *without* a fuse to shunt it.

Current-Carrying Capacity of Earthing Resistance.

It will be noted that the current which the resistance is designed to pass (under 230 volts) should bear a definite relation to the current at which the smaller sizes of distributor fuse are set to blow.

If primary importance is to be given to the prevention of the blowing of distributor fuses (due to "earths" in distributors, or on premises of large consumers), then the resistance must not allow a current to pass sufficient to blow the smallest distributor fuse—or, if the section be fused from both ends, the pair of fuses.

On the other hand, if the earth potential is to be kept, at all costs, as near to the neutral potential as possible, the resistance must be as low and have as large a current-carrying capacity as possible; but in this case we shall have distributor fuses—perhaps even feeder fuses—blowing on the smallest provocation.

Taking into consideration the fact that, with the panel devised by the author, the engineer can blow any distributor fuse (on a faulty distributor) at discretion, the safest course would appear to be to design the earthing resistance so as to *save* the distributor fuse or fuses, and to connect an alarm bell between the neutral 'bus-bar and earth, to ring with, say, 50 volts. The engineer can then close the switch S, Fig. 10, when the bell rings, first through a fuse insufficient to blow the distributor fuses; and then, if this still fails to clear the fault, through a heavier one; or if the voltage is not much over 50, he may elect to risk leaving it alone.

Earthing the Neutral at Feeding Points only.

The argument for earthing at this part of the system is, the author believes, principally that currents from faults on consumers' premises would form *local* circuits from the faults to the nearest earth connection, instead of, as now, having to traverse the whole town in order to get to the generating station. There would thus, it is argued, be less probability of interference with telephone circuits, gas and water pipes, etc.

The argument appears to be intended to apply only where there is a *completely* earthed neutral over the whole distributing system (the

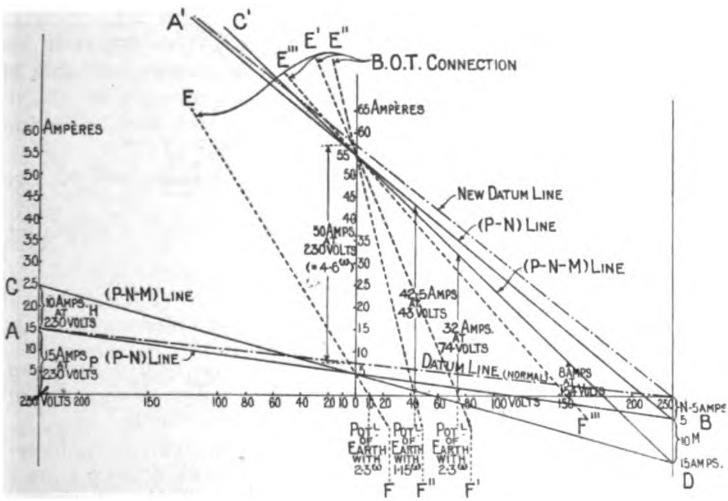


FIG. 13.

author shows later that it does not altogether hold here either). For if there be any resistance inserted—the diagram (Fig. 13) shows that a comparatively small "outer" leak will divert the potential of the earth by, say, 100 volts from that of the neutral.

The result of this will be that not only will the local earth plate of the particular section of distributing system be thus called into operation, but the whole of the other earth connections as well, thus setting up a network of earth currents all over the city.

Fig. 14 shows this condition of things, and the connections at the station for the author's test. It also suggests the undesirability, where there are substations in a town, of interlinking the networks supplied by these substations with that supplied by the main station, or with one another.

Risks with the Neutral Completely Earthed.

If, to avoid the difficulty described above, we cut down the resistance materially at the earthing points, we come to what is practically a *direct* earthing of the neutral at each distributing centre. It is true that we have now practically eliminated the chance of a consumer's fuse blowing under the conditions of Fig. 10; but have we not jumped out of the frying-pan into the fire? For it is impossible to conceive that the whole of the feeding centres of the town will always, as regards their neutrals, be at the same potential above or below the earth *except* by the flow of large earth currents from one centre to another.

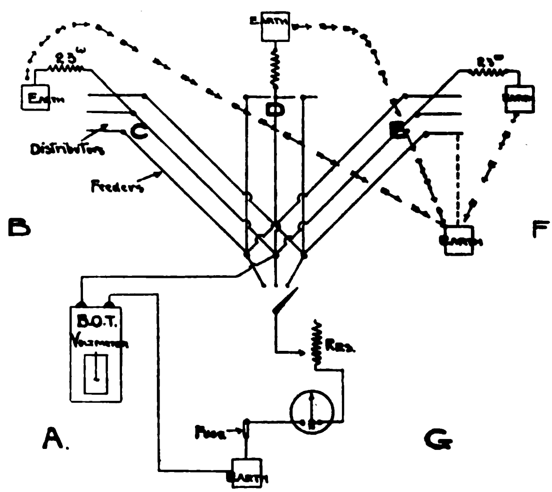


FIG. 14.

We shall have *invited* this by reducing the resistance so low between neutral and earth at the various centres; for the neutral feeders all come off a common connection at the generating station, and the "drops" in the feeders cannot conceivably be all equal.

The argument still holds to some extent, even though the neutrals be earthed continuously throughout the distributing system.

Again, all the disadvantages enumerated earlier against the reduction of the earthing resistance at the station still hold in their most aggravated form.

Testing with Neutral Completely Earthed.

It looks as if any attempt to measure the insulation resistance of the outers under such conditions would be unsuccessful, without disconnecting sections one by one.

The importance of being able to measure the insulation of, and to

localise faults on, each pole in turn, by a momentary earthing of one of the others, can hardly be over-rated.

Hence the use of a bare neutral distributor will, on this score alone, be distasteful to the average station engineer.

Again, since the state of the insulation of the "outers" is unknown, there may be considerable leaks developing all over the system, with the insulation gradually falling; but nothing will be known of it (the B.O.T. Ammeter has been "scrapped") till it becomes sufficiently accentuated *in one spot* to cause a fuse to blow.

Thus the insulation will get lower and lower, with no means of checking, or putting suspected parts under sufficient pressure to break down the fault.

A system which keeps the "outers" *up to a definite standard* seems to the author the only possible safe one, and this is not to be obtained where the neutral is completely earthed; nor where the earth connection, if *direct* to earth, cannot readily be removed by the station engineer for purposes of testing.

Conclusion.

It seems, on the whole, as though the most satisfactory all-round method were to earth permanently through a resistance and at the station.

When the connection is made through a fuse, without other resistance permanently in circuit, as is now rather general, it would seem that, the moment the fuse goes, all control of the rise of potential of the earth is taken out of the engineer's hand; and another fuse cannot easily be inserted unless the B.O.T. connection be entirely opened, when the voltage of the earth might be practically that of either of the "outers."

In conclusion the author hopes that this effort to draw discussion on a subject which seems to him to have been insufficiently ventilated, may not be considered a meddlesome interference with things which have long been settled.

APPENDIX.

NOTE I.—CHANGE OF POTENTIAL OF EARTH DUE TO FAULT ON EITHER "OUTER" MAIN.

Fig. 13 has been prepared to show the relation between :—(1) the current flowing through a fault on either "outer"; (2) the current in the B.O.T. Recorder; and (3) the rise of potential of the earth itself as compared with neutral B/B potential.

The fault corresponds with a momentary demand of about 34 amperes on the positive side of the station (or 39 amps. if we *include* the normal positive leak), the actual current through the fault being given by the ordinate enclosed between the new "datum line" and the old, at the proper potential (viz., 74 volts).

The lines E′ F′, E″ F″, E‴ F‴, correspond respectively with 2·3 1·15, and 20 ohms in the B.O.T. connection; and the potentials of earth are given by their intersections with the base line.

The normal position of the P—N line is shown by AB and the temporary position, due to the fault, by A′B.

The potential of earth, due to the fault, changes by 64· volts when 2·3 ohms are in the B.O.T. connection and by 30· volts when 1·15 ohms are employed.

If 20 ohms be employed in the earth connection—a not unusual value—the rise of potential, due to the fault, is no less than 145–150 volts.

The currents traversing the B.O.T. ammeter are also clearly shown.

In Fig. 11 B's fuse *f* would carry, or blow with, the 34 amperes, there being 2·3 ohms in the station earth connection.

Mr. Raphael. Mr. F. CHARLES RAPHAEL (*communicated*): Mr. Taylor has been kind enough to mention in his paper a method of testing the insulation resistance of networks during working which I suggested six or seven years ago. At that time I was preparing the book to which he alludes in his paper, and I made inquiries to ascertain what periodic tests were being made of the insulation resistance of networks. I was then rather in the position of a specialist, being usually only called in to locate the trouble and operate when the case had reached a critical point, and I was anxious to learn from the family practitioners how they diagnosed the disease of mains breakdown in its incipient stages. To my surprise I ascertained that the testing of networks for insulation was comparatively rare. The two or three engineers who did test them employed Frisch's method of connecting a voltmeter or ammeter between each main and earth when, as is well known, the insulation resistance of the whole network is calculable from any two of the readings.

Just then the 2 × 220 volt three-wire network with the neutral conductor earthed at the station was coming into vogue, and I therefore suggested the middle-wire ammeter method of measuring the insulation of the network mentioned by Mr. Taylor. Perhaps I may be allowed to explain here what this test is, as I am bound to confess that I did not recognise Mr. Taylor's Fig. 5 until I read in the foot-line that it was "Raphael's test," and it therefore may not have been clear to others either. An ammeter (either having a long range or appropriate shunts) is connected between the middle wire and earth through a resistance which is normally short-circuited. To make the test, the short circuit is removed, and a reading d_1 is taken. Then the ammeter and resistance is shunted with a resistance equal to the series resistance *plus* the resistance of the ammeter, and a second reading d_2 is taken. If r is the resistance of the ammeter *plus* its series resistance, the insulation resistance of the network is $\frac{d_1 - d_2}{2\,d_2 - d_1}\,r$. This method would appear to be applicable without the second ammeter, which Mr. Taylor designates "Board of Trade" ammeter in his Fig. 5. The resistance r would have to be of the same order as the insulation resistance of the network, and thus it must be normally short-circuited, as the function

of the earth on the middle wire is not fulfilled unless the resistance of this earth connection is a fraction of the fault resistance of the other mains. Mr. Raphael

I do not know whether this suggestion has been acted on to any great extent. I believe not, and that, when tests are taken—which is rare,—the earth on the middle wire is removed for a few moments, and Frisch's test is made. It may be noted that it is only necessary, in making Frisch's test, to earth two (any two) of the three wires through an ammeter or voltmeter, for the insulation resistance—as well as the reading which would have been obtained from the third wire—is calculable from the two readings.

It appears to me that, whatever method is employed for measuring the combined insulation resistance, this insulation resistance compared with the middle-wire ammeter reading will indicate on what main a fault has developed. Normally, for instance, the current through the middle-wire ammeter is *from* the middle wire *to* earth, indicating that the insulation of the negative main is worse than that of the positive main. Suppose this to be the case, and that the test of the combined insulation resistance one day gives a lower result than usual: if this is accompanied by an increase in the middle-wire ammeter reading, it indicates a decrease in the insulation of the negative. If, on the other hand, the middle-wire ammeter reading is below the normal, in spite of the decrease in insulation, the fault will be on the positive or neutral, the effect of a fault in the neutral wire upon the ammeter deflection being relatively less than a fault in the positive.

Coming to Mr. Taylor's suggestion, I must own that, with the limited time at my disposal, I have been unable to understand entirely the method he proposes. Has he checked his graphical explanation by an analytical proof, or by employing Mr. Alexander Russell's ingenious load diagrams? Perhaps in his reply to the discussion he will be good enough to make his method a little clearer. If he is really measuring the current leaking away from each main separately, his test should be most useful; but, if his method is a rough approximation only, and is influenced by the load on the network, a simple method such as Frisch's or "Raphael's" is preferable in my opinion. A momentary disconnection of the earth on the middle wire for the former method is not likely to be attended with serious consequences, and a momentary increase in the resistance in the middle-wire earth for the purposes of the latter method would surely be quite harmless.

Mr. Taylor has done good service in calling attention to the necessity of testing electric light networks, and I trust that his paper will not lead to the opinion that such tests are complicated or difficult to carry out. The contrary is the case; testing the insulation resistance of a network during working is one of the simplest electrical measurements.

Mr. ALEXANDER RUSSELL (*communicated*): I regret that I shall be unable to be present at the meeting, especially as there are one or two points in the paper which I fail to grasp. The diagrams would be so much more easily understood from Mr. Taylor's explanations. The absence of formulæ also makes it difficult to follow the methods, and makes it almost impossible to gauge their accuracy. I have attempted Mr. Russell.

Mr. Russell. to supply some of these formulæ with, however, only partial success. My attempts will enable Mr. Taylor to see whether I have understood him or not, and may probably be of assistance to others. The author's solution is deserving of the most careful study by station engineers.

In my paper published in the *Journal* and referred to by Mr. Taylor it is shown that if we make an artificial leak to earth from any of the mains, and if $V - V'$ be the simultaneous change in the P.D. between each of the mains and earth, then

$$\frac{V - V'}{C} = F,$$

where C is the current in the leak, and F is what is called the insulation resistance of the network. For various reasons the value of F is always altering slightly, so that a very accurate measurement of it is not wanted.

Now, since the earth connection of the middle is an artificial leak, therefore

$$\frac{V_2 - V'_2}{C} = F.$$

Where V_2 is the P.D. between the middle and earth when the earth connection is removed, V'_2 is the P.D. between the same points with the earth connection in its place, and C is the current in the earth connection. If we plot a curve with V'_2 for abscissa and C for ordinate, then we get the line C D in Fig. 1. If we alter the resistance of the earth connection, then

$$\frac{V_2 - V''_2}{C'} = F,$$

and hence

$$F = \frac{V'_2 - V''_2}{C' - C}.$$

The drawback to this method of measuring F is that $V'_2 - V''_2$ is only about 10 volts, and it is not a steady voltage. Also, since F is about 10 ohms, $C' - C$ is about an ampere, and could not be determined with any great accuracy. I should certainly not use this method.

Another method—and this, I think, is the method Mr. Taylor uses—is to make an artificial leak on either of the outers. In this case we have

$$\frac{V_2 - V'_2}{C} = \frac{F R}{F + R},$$

where C is the current in the leak and R is the resistance of the earth connection. This is the equation to the line E F in Diagram 1. Since we can make $V_2 - V'_2$ equal to 200 volts or so, we can determine $\frac{F R}{F + R}$ easily to within two or three per cent. Hence, unless F is large compared with R, we can determine it approximately when we know R.

It seems to me that it is unnecessary to worry ourselves about how to measure the insulation resistance with the earth connection in its position, seeing that it is perfectly simple to open this connection during

Mr. Russell.

the few seconds required to measure F. In the network considered the potential of the negative outer would then be — 280 volts, and this is not very alarming. The author seems to have had the neutral at 200 volts, and therefore the P.D. between the negative outer and earth must have been — 430 volts during his test.

I hope Mr. Taylor will explain a little more fully the principle of the method he uses for measuring the leakage current in the middle main, as if it can be done accurately, or even if it can only be done roughly, it represents a very considerable advance in our knowledge. It is easy to devise theoretical methods of doing this by keeping the two sides of the three-wire system at different potentials during the test, but the only methods known to the writer are too elaborate for practice.

The author seems to put a resistance in series with the neutral leaks, but as this resistance would be traversed also by the consumers' out-of-balance load, and as its resistance is very small compared to the resultant leak on the middle main, I fail to see how he manages to separate out the middle leak.

In most three-wire networks, when we alter the potentials of the mains, the fault resistances of the three mains vary, although the insulation resistance F of the mains remains the same. Hence we are not justified in assuming that the resultant leakage current from a main and the wires connected with it varies as its voltage from earth.

Since the distributing mains are underground and cannot be inspected, it is of vital importance to the working of the station that they should be subjected to periodical electrical tests. Mr. Taylor's testing panel is therefore a step in the right direction, and is deserving of the highest praise. Even if he has not succeeded in separating out the three leaks, we can determine the insulation resistance of a network rapidly by its means, and an inspection of these records will be of far greater value than an inspection of the record of the leakage current in the earth connection.

Mr. Trotter.

Mr. A. P. TROTTER said they were greatly indebted to Mr. Taylor for the paper, and also to those members who had asked him to give further explanation; for he had read the paper through twice, and he had been greatly puzzled by Fig. 1; but a great deal of it was made more clear by the explanation of the diagrams placed before them that evening, and the way in which Mr. Taylor described how the potential of the earth was pulled over in one direction or another by the ammeter was very interesting. He only wished he could follow how the ordinary out-of-balance current affected this; he did not quite see how that would be. He should understand it in a perfectly well-balanced circuit—however, he would not go into details on that matter. He was puzzled very much over what was the meaning of the height of the ordinate (A_2) in Fig. 1. Under the normal circumstances, when there was no leak at all, Mr. Taylor began with the ordinate and a slope to the datum line. There was a normal diagram with no leaks at all, and then there began to be slopes representing the leaks. He was glad Mr. Taylor had called attention to Mr. Russell's paper in Vol. 30 of the Institution *Journal;* it was an extremely interesting one, and most

Mr. Trotter. unfortunately was not in the index of that volume. It was a paper attached to No. 148 of that volume. Mr. Russell dealt with the problem like a steelyard. He took the centre of gravity as the neutral point at which, if you made a connection, there would be no leak; and he took the faults as loads on the bar, and treated them from the point of view of moment. He (Mr. Trotter) thought Mr. Taylor's method of diagrams, *when fully explained*, might be a still better way. Some people were more fond of algebra; but he was one of those who preferred a diagram when he could understand it. Mr. Taylor described the various ways in which the stations were earthed. He (Mr. Trotter) had to go into a good many stations and he very often asked the engineers how they earthed their middle wire, because he wanted to know; though it was not part of his duty because, fortunately, there were no Board of Trade regulations describing how it should be done. The general principle, he believed, of connecting the middle wire was to prevent any consumer getting more than a 250-volt shock. He believed that was the object, because the regulations began by saying he must be liable to no more. Of course, if there was a three-wire network, and there was a leak on the negative, up went the positive, and a man might get a shock off it. There was no harm in opening the earth connection at the proper time for a few seconds, but there was the stress you put on the wiring; a bigger stress was put upon the wiring than it was usually intended for. The use of the ammeter was not by any means universal. He came across works the other day in charge of a young engineer where there was no ammeter, no fuse, no switch—but the earth dead connected up. He hoped it might be so for long, but he fancied the engineer had something to learn, and he would no doubt have recourse to one of these devices. Some time ago he (Mr. Trotter) had to do with a very serious gas explosion. The gas company declared that the electric mains had exploded, and laid it all down to them, and he had to investigate it. He went to the works and asked how their middle wire was connected. It was connected to a recording ammeter; they showed the record for the day with the line dead straight and at zero. He asked the gas company if they had any instrument that would show their leaks, and they had not got one. One of the first recording ammeters he saw was at Glasgow. Mr. Chamen had found it most useful in tracing the leaks. He imagined that the use of that device would become very much more common than it was now. He once discussed what there should be in addition, at a meeting of the Municipal Engineers, that being, he believed, the first occasion on which the subject had ever been dealt with, though it was a most important subject. It seemed that there should be a resistance, otherwise there would be a dead short; such a resistance should be provided that at all events the plant could handle the current; some engineers suggested 10 or 20 ohms resistance. This was too much, and would defeat the object of earthing. He thought that the normal condition should be a dead earth on the middle wire, and a circuit-breaker set to open with a heavy current, throwing in a resistance and giving an alarm signal, and perhaps altering the sensitiveness of the recording ammeter,

Then came the question, if there were a heavy leak on the negative, how much would the positive go up? As Mr. Taylor had said, putting that resistance in would hold the middle wire down, and Mr. Russell went so far as to say that he would like to put the resistance in the sounder main to hold it down. He treated it from the point of view of a balance; if a heavy leak came on and pulled it down, he would like to put an artificial leak on the other end to hold that down; but a smaller leak at a greater leverage. He said it would consume so many kilowatts, and those might be useful in the station. But he (Mr. Trotter) thought no engineer had ever driven his pump, off that source of energy. He asked the people who had suggested 10 or 20 ohms in the earth circuit what they would do if there were a bad fault. Would not the sounder main go up above 250 volts? Mr. Trotter.

Mr. Russell's paper enabled one to calculate with some trouble, and he hoped that Mr. Taylor's paper would, when carefully considered, enable one to calculate with more ease. What was the maximum resistance that could be put to earth so that the sounder mains should not rise more than 250 volts above earth when a heavy leak occurred upon the other one? One railway company objected to some people putting their middle wire to earth at all; they said they would disturb their signals very much, but they added that if the people in question would put 1,000 ohms between there and earth, they would not raise any further objection. He wished to raise a little protest about any fuses or switches at all in middle wires. These troubles, it seemed to him, would be got over by considering the middle wire was at earth potential. The only way in which it could differ from earth potential was by a few volts owing the drop due to the current itself. If a leak occurred in a consumer's house, as was shown in one of the diagrams, what harm could happen as long as there was no switch and no fuse between that leak and the middle wire?

Mr. TAYLOR: Are you alluding only to fuses on consumers' premises or in the distributing main as well? Mr. Taylor.

Mr. TROTTER: Anywhere. Mr. Trotter.

Mr. TAYLOR: Because no fuses are shown on the neutral distributing main. Mr. Taylor.

Mr. TROTTER said it was rather startling to some people, but he believed Major Cardew held from the first, and he knew a good many engineers also held, that there should be no fuses and switches at all on any wire connected with the middle wire; let it all be considered to be an earth potential. Although he regarded that as earth potential, he was one of those who held very strongly that the middle wire should be earthed at one point only and insulated at all other points, as the Board of Trade asked. There had been a good deal of talk lately over the German system of abandoning insulation altogether on the middle wire, and having it earthed all over the place, but Mr. Taylor showed one or two reasons why that would be undesirable. Under such a system it would be impossible to make any tests at all; there would not even be the recording ammeter at the station to tell what was going on. He had hardly found any engineers who wanted that system except they wanted to pick up village lighting on the cheap. Mr. Trotter.

Mr. Trotter. It was fair to say that they claimed that leaks would develop rapidly into shorts, and that this result would tend to the happiness of the greatest number; but he was not convinced. But they were in the habit, he believed, of putting in insulation in excess of the work it had got to do. Why insulate for 250 volts? It was never going to get that; let them insulate it reasonably. As Mr. Taylor had said, if they set up a network of earth currents all over the city, and could not get at them to test them, it would be liable to give rise to very serious difficulties. It was quite a common practice to open the earth connection for making a test, but if Mr. Taylor's paper would enable engineers to make their tests without opening the earth connection, he thought a very great step in advance would have been made.

Mr. Duesbury. Mr. T. DUESBURY said that he could thoroughly endorse Mr. Taylor's reasons for a new test. He regarded the disconnection of the middle wire from earth for testing purposes as inadvisable, as it threw a great strain on the wiring. The knowledge that in the test described by Mr. Raphael the combined insulation only could be obtained, had, despite the regulations of the Board of Trade on the point, led most engineers to trust more or less in Providence, which trust was apt to be occasionally badly shaken. He could strongly endorse Mr. Taylor's views as to the middle wire permanently earthed through a low resistance being absolutely the best method of earthing, as he had experience of two other methods—earthed direct without any fuse, and earthed through a low resistance short-circuited by a fuse. It was unnecessary to consider the first, as the foolishness was apparent. The second method had one very weak point, that the advantages of low resistance were only utilised in the case of a fault sufficiently bad to blow the fuse, and consequently cut in the resistance. For some time, he ran at Sutton Coldfield with the middle wire directly earthed, but during the last nine months he had inserted between the middle wire and earth connection a resistance of 4 ohms, able to carry 60 amperes continuously, and he could confidently say that the number of cases of consumers' main fuses blowing had decreased by at least 50 per cent. He could also speak of the value of the recording ammeter in the way of locating small faults. On account of the big earth currents which must flow between feeding-points, he regarded the earthing of the network at feeding-points as altogether wrong, and he thought, if anything, he should much prefer the middle wire earthed throughout its whole length. Although quite foreign to the subject under discussion, he should like to remark that in some cases too little attention was frequently paid to the method of making the earth connection itself, and consequently the earth plate had an appreciable potential difference to the earth surrounding it. He recently heard of a case where the engineer connected the middle wire to the exhaust-pipe system, and seemed quite pained when he had to buy new boiler blow-down cocks within twelve months.

Mr. Groves. Mr. W. E. GROVES (*communicated*): While fully appreciating the importance of Mr. Taylor's paper, and particularly of the analytical diagram, Fig. 1, I cannot regard the test as it stands as likely to be of any

great service for frequent station use—say, twice daily in the morning, and at top load. Mr. Groves.

It should be possible for a "switchboard attendant" or his equivalent to report the state of the insulation when required to do so, particularly when there are several stations or substations, and I am afraid if Mr. Taylor's test were used in this way it would too often produce unsatisfactory results. Of course the idea of discriminating between the fault resistances of the three poles is most attractive, but facts are of greater importance than figures.

Mr. Alexander Russell's paper referred to by Mr. Taylor is a most valuable one, and the simple insulation test described in it very strongly commends itself to me. It involves the opening of the earthing switch momentarily, and this switch could be controlled by a spring to prevent its being left opened accidentally.

Normally, the D.P. between neutral and earth, if the switch were opened would be less than that involved by Test No. 3. The last-named test also involves the flashing about of considerable currents and voltages to the detriment of instruments and switches; it should be therefore only resorted to when the insulation has fallen too low. Referring to Mr. Russell's simple formula $F = \frac{V_2 - V'_2}{c}$, $\frac{V'_2}{c}$ is the resistance of the coil in series with the B.O.T. instrument; the test therefore resolves itself into a reading of ammeter in the earth connection and a momentary breaking of earthing switch to read V_2.

It is an easy mental operation to divide the latter by the former and diminish it by R. If F is high and R low (say 2 or 3 ohms), the latter may be neglected so that F is simply $\frac{V_2}{c}$. If F is above the selected standard the test is completed. If the test shows that F has fallen too low, the faulty or the *most* faulty pole will usually be indicated by voltmeter. If there are faults on both sides the removal of the greater reveals the less.

Occasionally we may be confronted with the voltmeter refusing to move appreciably when the earthing switch is broken, which would mean that the P and N leaks were exactly balanced (a condition of things rarely existing in practice) or that M is faulty. In this case having the voltmeter in front of us reading near zero there is no harm in leaving the earthing switch open, as it can be closed immediately the volts rise. This would avoid heavy current through the B.O.T. instrument while you perform what is a rough Test No. 3. If the neutral is sound the flashing will not effect the neutral ammeter, if otherwise, a "kick" will result. If outers are at fault the ammeter on the pole opposite to that flashed to earth will "kick." With suitable arrangements the switchboard attendant can easily read $\frac{V_2}{c}$, and if he reports that the insulation is down, the analysis of F can be undertaken by the mains superintendent.

Obviously the essential difference between Mr. Taylor's and Mr. Russell's tests is that the former reads A_2 (vide Fig. 1) and the latter volts between neutral and earth when earthing switch is open.

Mr. Groves. Mr. Taylor does not read the cotangent the angle C D makes with the horizontal directly, and $A A_1$ and A_2 must be very accurately read, but neither does he open the earthing switch. Mr. Russell reads this cotangent more directly as the expense of opening the earthing switch. I do not think any apology for opening the earthing switch is necessary if the insulation resistance can be more readily ascertained by the operation, particularly as the switch need only be opened for a moment.

The testing panel as designed by Mr. Taylor lends itself admirably to the performance of Mr. Russell's test as well as that devised by Mr. Taylor. It also permits the modification of the test suggested above being very readily carried out.

As a record of change and occasionally indicating to what kind of apparatus a fault is due, the B.O.T. recording ammeter is valuable, but the fallacy of relying on it to indicate the state of the insulation does not require emphasis.

Concerning the method of earthing. There should be no sentimental objection to blowing a consumer's fuse if a fault should develop in his installation.

The earthing resistance should be sufficiently low to allow currents to pass which will blow, with perhaps a few exceptions, the largest consumer's fuse should his insulation break down.

Any fuse in the network should be sufficiently heavy to avoid risk of a faulty consumer putting his neighbours in darkness.

Earthing without control would render efficient supply impossible and bring the business into disrepute. It would be small satisfaction to consumers to be told that supply could not be given because of a fault for which they may be in no sense responsible. Consumers would often be at the mercy of the industrious navvy who may have inadvertently driven into the supply mains.

Mr. Ashlin. Mr. F. J. W. ASHLIN (*communicated*): The test for obtaining actual readings of neutral leakage on a three-wire system seems a distinct step in advance of what could be previously determined by known methods. Such a test panel should be a welcome adjunct to any central station, giving a station engineer a ready means of knowing the state of the insulation of the supply system at any time.

From practical experience of the use of the panel as described I think that readings taken when a moderate fault develops, *followed up by actual search to locate the leakage*, will in many cases save the ultimate annoyance of possible heavy short-circuits, sometimes blowing the feeder fuses at the station end during time of heavy demand.

I would point out that the test panel as described would not appear to be so necessary when a leak develops on any feeder, amounting to a "dead earth." Assuming a differential reading B.O.T. recording-ammeter is used, this will at once show by the deflection on which side the leakage is taking place, and the result can generally be seen at once on the feeder ammeter on the switchboard in the extra load recorded.

If a fault of this magnitude comes on, say, before or during heavy load on the station, the earthing resistance (as advocated by Mr. Taylor) must carry its full current the whole time until the fault can be located

or cut out. At such a time it would be an advantage to be able to insert other resistance in parallel with the station earthing resistance. Mr. Ashlin

If, by any chance, the earthing resistance is subjected to double the voltage for which it was designed, say, 400 to 500 volts, through, say, a complication in a street box, the consequences to the resistance itself would be rather disastrous!

As regards the instruments—ammeters and voltmeters—used on the test panel, these require to be particularly accurate and should be frequently calibrated, as the effect of "pulling the potential hard over" is rather severe on the instrument. Any error would apparently be multiplied considerably if referred to the lines of Fig. 1, and would give misleading results as to the actual amount of leakage.

Instead of an accumulator cell and ammeter for the neutral test (as the cell requires attention by a battery attendant), would not an ordinary small 2-volt cell be sufficient, with a voltmeter to measure the drop of potential?

Mr. A. M. TAYLOR (*in reply*): Mr. Alex Russell describes his own test, which I quite recognise as a most useful and simple one. It is one which the consideration of Fig. 1 led me to several months ago, before I had unearthed Mr. Russell's paper; but having set myself the problem of devising a test which should not interfere with the earth connection, I (perhaps wrongly) rejected it as a solution of the question. Mr. Taylor.

Mr. Russell suggests that my method is to make an artificial leak on one outer and measure the current in it. That is so, as regards the *first* part of my test, which only carries us as far as the obtaining of the joint insulation resistance of the three mains, indicated by the slope of the line (C D) in the diagram, Fig. 1.

The second part of the test is quite distinct from this, and consists of what we may call a "discriminating" test. By means of the artificial leak we can cause the potential of the earth to travel away from that of the neutral 'bus-bar to any desired extent—say 200 volts. This puts the neutral leak of the system under 200 volts, and if the insulation resistance of the neutral system were 10 ohms then 20 amperes would flow. This would increase or diminish the algebraic sum of the current in the neutral feeders by that amount.

Suppose that, prior to making the change in the earth potential, and immediately after making the first part of the test (which left the earth potential *at* that of the neutral 'bus-bar), the out-of-balance current of the station is found to be, say, 50 amperes, then, on closing the artificial leak so as to put 200 volts on the neutral leak, the momentary increase in the out-of-balance current will be 20 amperes, and on opening the artificial leak again it will diminish to its original value of 50 amperes.

We should thus know that the neutral leak alone had a resistance of 10 ohms; and, having previously measured the joint insulation resistance of the three leaks, it is the easiest thing to deduce the combined insulation resistance of the positive and negative leaks *without* the neutral leak.

Mr. Russell's question as to whether the current through the leaks really obeys Ohm's Law or not is a most interesting one; because, if it

Mr. Taylor. did not, it seems that all tests hitherto considered are valueless. I am glad to be able to assure Mr. Russell that it does. On a particular town's system, applying the "discriminating" test, I found the neutral leak to be :—

15	amperes	under	200 volts
$7\frac{1}{2}$	"	"	100 "
3	"	"	50 "

indicating—especially as the last figure could not be measured very exactly—a very good agreement with Ohm's Law.

Mr. F. C. Raphael suggests that by means of his test he can really discriminate between the leaks. The method he suggests is to measure the joint insulation resistance (F) of the three leaks, and compare this with the B.O.T. Ammeter reading.

In any case we only can by this method measure the *change* in the resistance of any one main—not its actual value. If things are to be kept up to a standard—the B.O.T. standard—we must be able to measure the actual value.

Mr. Raphael questions the correctness of the diagram Fig. 1, but I think the fact that the equations, both for Mr. Russell's test and for his own, can be deduced from it are a proof of its accuracy. Mr. Russell has apparently accepted it, for he has pointed out that the joint insulation resistance (F) as measured by his test gives the slope of the line (C D) in my diagram.

In reply to Mr. Raphael's inquiry whether the discriminating test is not affected by the load on the network, I may say that in the reply to Mr. Ashlin's remarks I have gone into this question somewhat more fully than in the paper itself.

Mr. A. P. Trotter asks the very pertinent question : "If we have a heavy leak on the negative, by how much will the positive 'bus-bar potential rise above that of the earth?" I submit that Fig. 1 fully indicates the principles on which we can determine this, and in Fig. 24 (shown among the lantern slides, and now incorporated in the paper) the actual rise of potential of the earth towards that of the positive 'bus-bar, for a given fault on the *positive* system, and for three different resistances in the B.O.T. connection, is shown clearly. Fig. 2 of the paper will help Mr. Trotter to apply this diagram in a similar way for the determination of the conditions accompanying the leak on the negative.

Mr. Trotter also asks what is the meaning of the ordinate (A_2) in the diagram, Fig. 1. It is the value of the current which must be put into the artificial leak (see reply to Mr. Russell) in order to bring the potential of the earth to that of the neutral 'bus-bar. In other words, it is the amount by which the normal positive leak is greater than the normal negative leak when both are under the same pressure of 230 volts, and is therefore $= (P - N)$. I am encouraged by Mr. Trotter's remarks to hope that the diagram given in Fig. 1 will prove useful to those engineers who like something which enables them to picture graphically what goes on, instead of having to arrive at it deductively from formulæ.

Mr. Taylor.

Mr. Dewsbury's experience is very interesting, as quite confirming the conclusions in the paper as to the advantage of earthing through a resistance alone, and with no fuse whatever in connection with that resistance.

Mr. Groves makes the remark that Mr. Russell's test is more convenient than mine, and is less complicated in the formula used.

The formula for my test is—

$$F = \frac{V_1}{\dfrac{A_2 - V_1}{2\,\omega}};$$

the resistance in the earth connection being made equal to 2 ohms. There is no great complication about this, and I think his complaint is caused by his setting off the *two* tests I suggest—the combined insulation resistance test *and* the "discriminating" test—against the one test of Mr. Russell. But to get the same information as Mr. Russell's test gives, it is only necessary to perform the *first* part of the test (see remarks under reply to Mr. Russell), and this consists of the simple observation of (V_1), the normal voltmeter reading, and of (A_2) the current in the artificial leak when we close the circuit of the same and adjust the sliding resistance switch shown on Fig. 7 of my paper.

On the question as to whether a discriminating test is always necessary, as a day-by-day operation, I am inclined to agree with Mr. Groves that it is not. It is merely useful in enabling us to know whether the insulation of the two *outer* mains comes up to a standard—say the B.O.T. standard of a combined leak not exceeding one-thousandth of the station output—and so preventing the mains superintendent from hunting for faults on the outers which the low insulation of the neutral has led him to imagine exist there.

Mr. Ashlin suggests a more easy way of measuring the neutral leak than that employed in my "discriminating" test. Such an arrangement as he suggests it was my intention to describe on the occasion of reading the paper; but it was necessary to postpone its description to another occasion on account of the lateness of the hour.

It is easy to arrange such a circuit as Mr. Ashlin suggests, *i.e.*, with a single Leclanche cell and a voltmeter, graduated in amperes; but the difficulty is the continually-varying magnitude of the out-of-balance current of the station.

The way in which this may be overcome is as follows: Off the plate resistance shown in Fig. 7 let there be taken 11 wires or tappings, thus dividing the resistance into 10 equal parts.

Connect the free end of No. 11 wire with a source of E.M.F. of 0·2 volt (a couple of small cells of different types set to oppose one another will do), then continue it through a central-zero voltmeter, sufficiently sensitive to read 100 divisions of scale with 0·2 volt, and again continue it to the central contact of a 10-way voltmeter switch, to the other points of which are attached the free ends of the other 10 wires. If, now, the voltmeter dial has been graduated to read 0 — 100 amperes then, with the switch on stop No. 1, the voltmeter reads

Mr. Taylor. $1^\circ = 0{\cdot}1$ ampere; and with it on No. 10 it reads $1^\circ - 1{\cdot}0$ ampere, and so far any intermediate value proportionally.

If the plate resistance $= 0{\cdot}02$ ohm then, when 10 amperes traverse it, the voltmeter will read zero when the switch is on stop No. 1; if 100 amperes traverse it the voltmeter will read zero when the switch is on stop No. 10, and so proportionately for intermediate values.

Take, for an example, the case where the normal out-of-balance current of the station is only 10 amperes.

Set the switch on stop No. 1 and the voltmeter—which is graduated, as before stated, in amperes—will read zero. Now apply pressure to the neutral leak (in the manner indicated in reply to Mr. Russell), and the *increment* of current through the neutral feeders, due to the neutral leak, is read directly on the voltmeter, remembering that the dial reading in ampere must be in this case divided by 10.

If 100 amperes had been the normal out-of-balance current of the station, instead of 10 amperes, we should have put the switch on to stop No. 10, and have read the leak current *direct* in amperes.

It is not necessary that the reading should be at zero to begin with; all that is necessary is to take the difference of the two readings obtained before and after putting pressure on the neutral leak.

In conclusion, I wish to thank the various gentlemen who have taken part in the discussion for the kind way in which they have received the paper.

MANCHESTER LOCAL SECTION.

THE ARRANGEMENT AND CONTROL OF LONG-DISTANCE TRANSMISSION LINES.

By E. W. COWAN, Member, and L. ANDREWS, Member.

(*Paper read at Meeting of Section, March* 3, 1903.)

It is proposed in this paper, after a general review of the points involved, to deal more fully with the regulation and protection of the lines by making certain suggestions with a view to the more certain maintenance of an efficient service; and especially with some of the conditions to which long transmission lines at comparatively high pressures are subject, whether underground or overhead.

GENERAL CONSIDERATIONS.

Pressure.—The maximum pressure, so far as we are aware, which has been actually in practical operation is 80,000 volts. The Standard Co. of America have operated on one of their lines for two hours in adverse weather at this pressure without any trouble arising. There is no reason why this should be the limit of pressure, as transformers have been worked well above 100,000 volts, and with liberal spacing of the overhead wires the electrostatic leakage can be sufficiently reduced. The capacity current increasing with the pressure must of course be reckoned with, and, if necessary, compensated for by suitable reactance coils in the way referred to later on. It is with large powers and long lines that economy requires the adoption of these great pressures. It has been contended that pressures above 10,000 volts will not serve any useful purpose in this country. We think that these expressions of opinion indicate a narrow view of the future development of electrical power. The essence of electricity supply lies in its distribution, and any factor which increases the distance, the economy, and the facility with which electrical energy can be transmitted greatly widens the field of its usefulness. We are not speaking of small powers, our ideas of "bulk" embracing more than a few thousand kilowatts; we are thinking of the requirements of the power user and of the necessity for concentration of large units at the centres of supply if advantage is to be taken of the use of gas fuel. Cheapening the outside works and reducing the losses of transmission, which is the result of the use of high pressures, greatly facilitates the exploitation of the area supplied. According to the development of demand other centres of supply can be installed, the raising of the necessary capital being then greatly simplified, not to say cheapened. We should point out that the extra outlay involved in the use of high pressures is trifling; it only affects insulation of line and transformers.

There is no reason why a scheme should not provide for the supply being transmitted at a low pressure in the early stages of its career, and when the requirements of the situation justified it, the pressure could be raised merely by an alteration to the step-up and step-down transformer connections. According to Mr. Parshall, 20,000 volts may be taken as the safe limit for underground cables; the cost of insulation and the capacity of the underground cable rendering the use of higher pressures prohibitive. There is a point in favour of high voltage for underground cables which should be borne in mind. Assuming the same energy transmitted by a cable, the heat energy developed at a fault is, from one point of view, inversely proportional to the square of the pressure. We consider, therefore, that the Board of Trade should allow greater energy to be transmitted by a cable with greater pressures.

Periodicity.—After much fluctuation the practice of to-day seems to be steadying down to a frequency of 50 to 60 for alternating currents. The Pacific Coast lines in California have adopted comparatively high frequencies—the Niagara Company standing almost alone with its low periodicity. It is interesting to note that out of seventy-three power transmission installations, thirty operate at a frequency of 60 cycles or over, and twenty-eight at between 50 and 60 cycles. It must be remembered that the higher frequency increases the charging current, the impedance drop, and is not so well adapted to motors or rotaries as the lower frequencies; at the same time lighting becomes practicable and the transformers are cheaper.

Lightning.—It is necessary in some countries to make very elaborate protection against lightning discharges. Atmospheric difference of potential can best be provided against by stapling a barbed wire to the poles and frequently earthing. The increase in capacity in the cables due to this wire is said to be not appreciable. Disruptive discharges are dealt with by lightning arrestors, of which there are many designs. The essence of nearly all types is the provision of a small inductance (kicking coil) on the generator side of the earth connection, in series with which the discharge part of the arrestor is placed. A large number of spark-gaps in series with a non-inductive resistance form the essential features of this part of the apparatus. For reasons stated later on horn break lightning arrestors should be avoided.

Earthing.—There is considerable difference of opinion as to the advantages and disadvantages of earthing the neutral point in a polyphase system of distribution. It appears to us that the advantages of earthing are considerable. In an unearthed system the static capacity between wire and earth with high pressures becomes a source of danger, and this static capacity may be 83 per cent. higher than it can possibly be if the neutral of a three-phase system be earthed. When the neutral is earthed faults are immediately detected, and must be removed. On the whole, the voltage available in case of accidental contact tends to be reduced by earthing the neutral point. We learn that the Lancashire and Yorkshire Company in their electric railway scheme are earthing the neutral point, and thereby making an

appreciable saving in its cost, which is another advantage of great consequence. The Cable Makers' Association have recently standardised a reduction of dielectric thickness between conductors and earth of approximately one-third when the neutral is earthed.

CAPACITY.

The charging current required for long lines even when fixed overhead is very large. A 100-mile line working at about 50,000 volts and with a periodicity of 50 requires a charging current exceeding 2,000 kilo-volt-amps. This is equivalent to the full current load of a 2,600 E.H.P. plant. Unless the capacity is neutralised by reactive coils it becomes uncommercial to transmit powers at this pressure of less than 3,000 kilowatts. The use of high potential reactive coils, which are made preferably without an iron core, and placed as a shunt across the mains at suitable positions on the line, is a rather expensive expedient and also involves the introduction of many points of possible breakdown of insulation which are better avoided. Further these coils should be disconnected as the load comes on. The charging current on underground cables is of course much greater than on overhead. The Deptford cables at 10,000 volts take a charging current, we believe, of 45 amps. = 450 kilo-volt-amps. Large synchronous motors on the line with their field strength suitably adjusted can be arranged to neutralise the capacity of the cable, but their field strength must be varied with the load on the line. An ideal arrangement would be to balance the constant self-induction by constant capacity and the variable self-induction by variable leading load.

Though this capacity current, being expended reversibly, does not represent proportionate loss in watts, it does involve considerable loss at light loads and also results in bad regulation, the leading current causing an alteration in the ratios of the transformers and in the field excitation of the generators. It should be noted that the current required to charge cables is greater when the current curve departs from sine form, and it has been stated that the charging current may be increased from 200 to 300 per cent. when the waves are jagged. As the load increases the power-factor also increases. In one installation, having very large capacity in the cables which we were connected with, the power-factor at full load was over 99 per cent. It is often said that capacity is an advantage in supplying the magnetising current for the transformers and for neutralising the self-induction of the line. This is true, but large capacity is nevertheless the cause of far more trouble than it saves. The Manchester 6,500-volt cables have a capacity of 0·23 mfd. per mile between one core and the other two.

Loss in line.—The loss in the conductors must of course be worked out for the greatest economy in each case, with due regard to the spirit of Kelvin's Law. In long lines the loss may be as much as 50 per cent. One hundred amperes is about the limit which can be transmitted on one line from 100 to 200 miles long, owing to inductive drop which, with a 200-mile line at 60 cycles and 50,000 volts, may amount to no less than 50 per cent. The necessity for high pressures to reduce the current

upon which the inductive loss per mile depends, becomes, therefore, very evident when the length of the line is great.

Overhead and Underground Conductors.

For long distances underground cables are inadmissible, not only on account of their cost, but also because their capacity with the high pressures necessary results in an impracticably large condenser current. It has been very clearly shown by our Chairman, Mr. Earle, and also by Mr. Stewart, that a point is soon reached at which the cost of insulation is so high in proportion to the cost of copper in underground mains, that no economy results in transmitting energy at a higher pressure than a certain critical ascertained "cheapest" pressure. But this "cheapest" pressure will be further reduced by taking into consideration the reduction of charging current which will result from a lower pressure. The saving will be effected under the following heads:—(1) Reduced dielectric loss in cable; (2) charging current C^2R losses in copper of cable, transformers and generator; (3) standing losses in light-load engine which must be larger the greater the charging current. Proper value must be given to various factors, such as the hours of light load (charging current is practically eliminated at full load), reduction of condenser current due to inductive load, etc. We have worked out the capacity current at a frequency of 50 from data obtained from a length of vulcanised rubber concentric (37/15), and find that the charging current at 30,750 volts on a single 27½-mile length of such cable with the outer earthed would amount to over 4,000 apparent kw. It will be at once seen that no possible distribution could be carried out on these lines.

It appears to us that long-distance transmission lines should always be run overhead when crossing open country. Mr. Earle has calculated that the cost may be about one-third of the cost of laying the cables underground, but in addition to the saving in cost, there is the accessibility and ease of repair, and the possibility of using more economical pressures with the greater economy in running at light loads owing to the greatly reduced capacity current.

Against the use of overhead wires there are three objections:—

(1) Danger.
(2) Unsightliness.
(3) The Board of Trade?

On the question of danger we do not think that serious consideration need be given to the risk of accident from falling wires. There is a small risk, but with a well-engineered line it is very small, compared with many other risks which the community must and do submit to in the general interest. Kite-flying in the neighbourhood of high-potential lines on a wet day would become a dangerous form of amusement, and ballooning would also prove an exciting sport. There is no doubt that if an air-ship became entangled with a 50,000-volt line it would suffer rapid deterioration.

On the question of appearance, these lines would not look worse, but rather better, than existing telegraph and telephone lines.

Finally, there is the Board of Trade. In their letter some time ago to the Chairman of the London Chamber of Commerce the Board of Trade intimated that they were prepared to consider overhead schemes. We therefore consider that there is a fair prospect of obtaining consent to a form of distribution which can be, we think, readily proved to open out much greater possibilities in the direction of cheap power, which means cheaper production and consequently greater prosperity in the country.

Overhead Construction.

Poles and Conductors.—The poles are generally of wood from 35 to 40 feet in length, and spaced about 50 to the mile. In some instances steel towers are being used which get over the difficulty of the decay which takes place in the part of the pole underground. The steel towers in the case of one 60,000-volt installation in Mexico are placed 440 ft. apart. It has been stated that the cost of these towers does not exceed that of a first-class pole line. As an instance of what can be done, there is a single span of 4,000 ft. on the Bay Counties Co.'s line in California. The insulators are made of glass, vitrified porcelain, and of brownware. The latter are said to be less alluring to the sporting instinct, and the glass insulators have an advantage in their transparency, annoying the spiders which prefer to spin their nests in the dark. Porcelain must be thoroughly vitrified. A $\frac{3}{8}$ in. slab of unvitrified porcelain punctured at 17,000 volts under test, whereas a piece of well vitrified porcelain $\frac{1}{8}$ in. thick withstood 49,500 volts. The insulators for high pressures are generally made with three petticoats. For such pressures as 60,000 volts they will be about 14 in. in diameter, and placed about 10 feet apart. For 30,000 volts they will be about 7 in. diameter. Aluminium wires have been used in some cases, notably by the Standard Company in America. The weight of these conductors for the same conductivity is about half that of copper, the strength about $\frac{5}{8}$, and the diameter 30 per cent. greater. The question of durability can only be settled by time, but the lighter weight enables the spacing of the poles to be increased or the safety factor to be higher. An incidental advantage electrically is that the electrostatic leakage is less with aluminium cable, as its surface is larger.

Electrostatic Leakage.—The electrostatic leakage, taking the form of a brush discharge between wires, with high pressures is considerable, and the use of conductors of less diameter than $\frac{3}{8}$ in. becomes prohibitive.

A test on an actual line showed loss of energy due to air leakage with 47,300 volts to be 1,215 watts per mile when the distance between the wires was 15 inches. When this distance was increased to 52 inches the leakage was reduced to 122 watts per mile. With high pressures it is usual to place the wires about 10 feet apart.

Inductive Drop.—Self-induction and mutual induction must be taken into consideration, and on long lines both may have considerable

effect. Mutual induction can be neutralised to a large extent by suitable transposition of the wires, each case being worked out according to the circumstances. In the instance of two overhead three-phase systems, the mains of each system should be spiralled, the pitch of the one being three times that of the other. The mutual induction will then be zero. The drop due to self-induction is compensated for to some extent by the capacity of the line.

Electrostatic Induction.—This form of induction affects neighbouring telephone lines and may make them unworkable. It is not easily dealt with, and such lines should give each other a wide berth in order to avoid trouble.

UNDERGROUND LINE CONSTRUCTION.

Underground cables are all but universally used at the present time in this country for the distribution of electrical energy, excepting the trolley lines for electric traction. The system which has found most favour is the so-called "solid system." A typical method of laying has been adopted in Manchester, where the high-pressure conductors are laid in cast-iron troughs filled with bitumen. The figures and curves relating to cost given in Mr. Earle's paper, before referred to, must be corrected, owing to the fact that they were based upon a thickness of insulation which it was assumed the Board of Trade insisted upon. It has since been ascertained that the regulation of $\frac{1}{10}$th in. thickness of insulation per 1,000 volts does not apply to the extra-high-pressure cables, and that each case will be considered on its own merits. One cable maker informs us that he is of opinion that $\frac{1}{2}$ inch radial depth of dielectric is sufficient to withstand 60,000 volts pressure, but he is unable to say whether the insulation would withstand such a stress for any great length of time. The Cable Makers' Association have recently standardised a thickness of little over $\frac{3}{8}$ inch for 10,000 volts working pressure.

We now pass to the second part of our paper, dealing with Regulation and Protection of High Pressure Lines.

In 1896 one of the authors of this paper, in conjunction with Mr. A. Still, submitted a communication to the Northern Society of Electrical Engineers, a section of which dealt with feeder regulation with static boosters. Since that date certain improvements have been made in the variable induction type of regulating transformer, whereby its inductance and magnetising current have been substantially reduced. In the discussion on the paper referred to, Mr. Rider, Mr. Mordey, and others expressed the opinion that the system recommended was the best method of regulating. Briefly this system, which has been widely adopted, consists in connecting the feeder in series with the secondary of a transformer, the pressure across which can be varied by operating a hand wheel. In supply works where there is only one transmission line such apparatus is not needed, as the bus-bar pressure can readily be varied; but in cases where there are two or more transmission lines of different length or load, independent regulation of each line is necessary. There is practically no loss in

efficiency in augmenting the pressure on a line in this way, the losses in the booster being sometimes less than the saving in supplying the 'bus-bars at a lower pressure. This is owing to the core losses in the

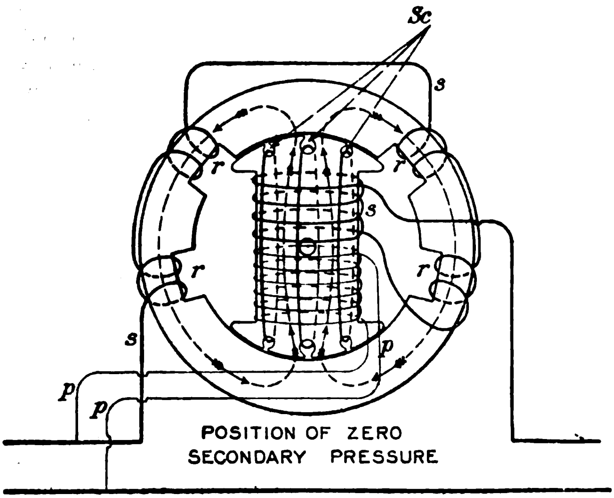


FIG. 1.

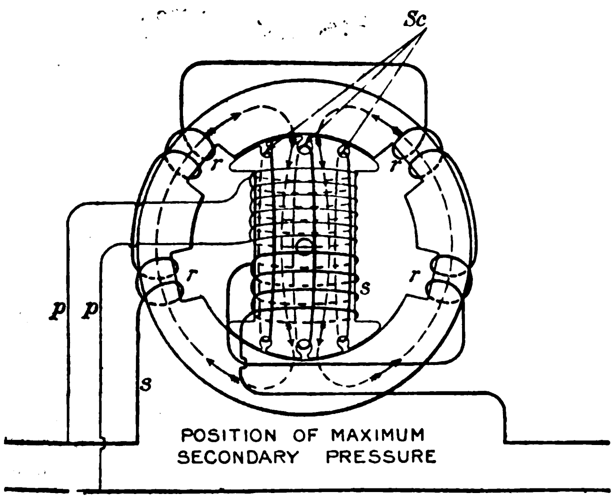


FIG. 2.

generators varying approximately as the square of the induction. The mass of iron in generators will, of course, greatly exceed the iron in the boosters.

Figs. 1 and 2 show the winding and arrangement of core of the

improved Variable Induction Transformer, in the position of zero secondary pressure. Instead of the secondary winding being wound entirely upon the ring, it is wound half on the movable core and half on the ring. The primary winding is wound as before on the movable core. The result of this arrangement is that the magnetic lines induced by the primary winding cut the half of the secondary wound on the movable core in a positive sense, and the half of the secondary on the ring in a negative sense in the relative position shown in Fig. 1. The resultant E.M.F. in the secondary is therefore nil. In Fig. 2, however, the movable core has been rotated through an angle of 180°, and the magnetic lines cut both the secondary windings in a positive sense, the resultant E.M.F. being the sum of the two, and therefore a maximum. In intermediate positions, intermediate secondary pressures are obtained.

It will be at once seen that there is practically no magnetic leakage between the primary winding and the half of the secondary winding on the movable core, and that the number of secondary turns on the iron ring being half of the total, the tendency for magnetic leakage to occur at the air-gap is proportionately reduced. The result is that there is only a total drop of six to seven per cent. on the secondary between no load and full load.

A further improvement consists in fixing shading coils on the movable core in the positions shown, and marked *s c* in the diagram. These shading coils neutralise the inductance of the secondary circuit when the movable core is in intermediate positions.

Lastly, the slots in the ring which contain the secondary coils are so placed that the area of gap between movable core and ring is as large and as equal as possible in all positions, thereby keeping the magnetising current as low and as constant as possible.

The result of these improvements has been to bring the apparatus up to a standard which leaves very little room for further improvement.

Before describing certain special apparatus for the protection of transmission lines, we have thought it worth while to discuss the dangers to which such lines may be subjected under working conditions :—

Abnormal Pressure Rise in Transmission Circuits.

A great deal has been written upon the subject of rises of pressure which take place under certain conditions in long circuits having considerable self-induction and capacity. Mathematicians have figured on the subject at length, and experimentalists have reproduced many of the phenomena accompanying line disturbances. At the same time the subject is enveloped in a certain amount of mystery, and cannot be considered as fully understood. It is usual for engineers to speak glibly of resonance and capacity effects, and they understand the effect of the equivalent of the inertia of the current in the shape of self-induction. It is generally appreciated that all three of these influencing factors combined in certain relations are responsible for the truly terrible rises of pressure which sometimes unexpectedly occur.

It is important that engineers should understand as far as possible the physics of these phenomena, and we have therefore dealt rather fully with the question, in the hope that, to a small extent, what we have written, and, to a large extent, the criticisms which we trust will follow from other engineers may tend to the elucidation of some of the mystery. In the first place, the rises of pressure are beyond question great in destructive effect. We have experienced them ourselves many times. In one case the opening of a switch on load caused the instantaneous breakdown of four transformers, and an alternator armature to flash to its field poles. In another case the rupture of a fuse in a sub-station caused the most violent rise of pressure at the transmitting end of the line, explosively destroying an electrostatic voltmeter and doing other damage. A transformer at Hastings broke down, and presumably was the cause of the simultaneous breakdown of another transformer, connected to it only through the station 'bus-bar by a three-mile length of conductor. On the Altrincham circuits it used to be a regular custom to examine the fuses in all transformers within a certain radius of any one transformer in which they had blown, and it was often found that a number of fuses had blown simultaneously. At the Paris Exhibition a man drove a nail into a cable, and it was simultaneously punctured at a point a mile distant. A rise of pressure of $\frac{1}{4}$ to $\frac{1}{2}$ a million volts has been observed on a half-mile H.T. cable with considerable self-induction when the circuit was broken, the normal pressure being only 10,000 volts.

Passing over the opening of circuits of large self-induction *per se*, such as field coils, etc., we will first consider the case of opening a circuit having self-induction and also capacity to an appreciable extent. In this case the capacity takes the place of the arc formed at the switch or fuse break as the equivalent of a relief valve tending to reduce the rise of pressure, and at first sight it might be thought that the presence of capacity was just what was wanted. Indeed, it has been pointed out again and again that underground cables having necessarily more capacity than overhead, are freed thereby from such severe rises of pressures. But the arc, when steady and maintained, is a far more efficient relief to the line than capacity. In the arc the electro-magnetic energy stored in the cable is discharged through resistance, and thereby doing work, is dissipated. But if capacity exists, the arc is abruptly extinguished owing to the rise of pressure sufficient to maintain it being checked by the flow of current into the condenser. The full amount of electro-magnetic energy stored in the cable will therefore be converted into electrostatic energy in the condenser. At the moment the cable was opened the condenser was charged by the normal pressure of the circuit, so that the charge it receives from the electro-magnetic energy of the line will, according to its measure, increase its pressure. It is easy to calculate what this rise of pressure will be if the data be given. But that is not all, the condenser differs from the arc in that it does not dissipate the energy put into it, but instantly returns it to the circuit to be reconverted into electro-magnetic energy. The process is then reversed again, and an oscillation set up between the electrostatic and electro-magnetic state at a rate depending

upon the natural period of oscillation of the circuit which will be slower the longer the circuit may be. The frequency will in all cases be very much higher than the normal frequency of the supply to the circuit. It has been shown that under certain conditions a pressure rise in *volts* may occur of *two hundred* times the interrupted current in *amperes*, and these conditions are such as may occur on commercial transmission lines.

It thus appears that to draw out a long arc at the switch contacts is the safest way of opening a circuit of high inductance, and in our opinion with continuous currents this is the best practice. With alternating currents, however, a new disturbing factor is introduced by the open-air arc. It is well known that an arc between carbons will emit a musical note if it be shunted by a condenser and arranged in series with a very small amount of self induction, such as will be obtained from the conducting leads or a coil of wire. This musical note is due to the arc being intermittent, and the rapidity of these interruptions may, at any rate in the case of an alternating-current arc, be very great—3,000 to 4,000 per second. Here then are all the conditions which are well known as the cause of pressure rise. In an induction coil or transformer the induced pressure increases proportionately to the frequency of intermittence of current or of alternation when the induction in the core is constant.

The intermittent arc at switch break has been compared to the Wehnelt Interrupter, the self-induction and electrolytic polarisation of the latter being replaced by the self-induction and capacity of the former. In one installation we have been associated with, the capacity of the mains was no less than 87·8 microfarads. It is not difficult to get some idea of the volcanic conditions of a circuit under such conditions, the roaring arc at switch or fuse kicking waves of E.M.F. into the circuit, which are met by surging waves of varying periodicity, travelling about the cables and their branches at a speed something less than that of light, causing resonant effects where their crests coincide and rises of pressure at every terminal point and every point where there is a change to greater inductance and less capacity. Such a storm of colliding E.M.F.'s will break down the insulation of any system. Arcs have been drawn out to a length of 35 feet under such conditions with 40,000 impressed volts and 150,000 volts pressure observed while the arc was flaring. We have no room on modern switchboards for arcs 35 feet in length, and to use an open break switch on high-potential circuits having appreciable self-induction and capacity is bad engineering. We may mention here that metal arcs are much worse than carbon, the conducting vapour of the latter tending to prevent the intermittent extinction of the arc. Soft carbon break would be the safest, and there is an open field for switch designers to construct an air break switch, the arc of which shall be maintained at gradual increasing resistance, and the first break in which must be the last. A low resistance intermittent arc is the worst of all for producing the above effects.

On all high-potential alternating-current circuits the oil break switch is being generally adopted at the present time. But an oil break switch,

though it prevents the formation of the dangerous intermittent arc, appears to be an unscientific method of opening any circuit with appreciable self-induction. The self-induction of the circuit being the same, it seems to us to be equally bad to open an alternating-current as to open a continuous-current circuit abruptly, whether under oil or by magnetic blow-out. It is true that there are many chances against opening the alternating current at its mean value, but at the same time, are there not some chances that it will open at the wave crest which is, with a sine curve, 41 per cent. higher than the mean? We are unable to see any physical difference between the suddenly opened alternating-current and the continuous-current circuit in respect to rise of pressure due to the accumulated electro-magnetic energy with which the circuit is linked if the current is the same in each case. At the same time, if it can be shown that the oil break switch *always* opens the circuit at a point in the current wave much below the mean, our objection would be withdrawn. We do not in any case contend that the oil break switch is not the best form for engineers to adopt at the present time for very high pressure circuits which must be opened under load, though water break is safer in cases where space can be afforded.

We have dealt with the most important results of current surging first, but there are other causes of rises of pressure which must be borne in mind. There may be a resonant rise of pressure, especially if the curve of E.M.F. and current departs much from true sine form. These rises, which are steady when the cause is steady, are due to interference between the generator waves and the waves of oscillation in the cable. It can only take place when there is capacity and self-induction, but may be set up by the fundamental waves of the generator or by odd multiple harmonics or overtones thereof. Resonant effects have been observed with continuous currents owing to slight waves being generated by the commutator. Rotaries have been known to produce resonance, their commutators being again the cause. The general result, however, of steady resonance is not serious, and the rise in step-up transformers due to the leading current will in general be many times greater than that due to resonance. Regulation is not easy when resonance occurs only at some critical speed.

While the opening of a circuit under load is the worst condition for causing rises of pressure, rises will also occur when an unloaded line is opened or closed. According to many authorities on this subject the rise cannot exceed double the normal pressure under these conditions, and it is easy to follow the reasoning on which this conclusion is based. When the switch on a "dead" circuit is closed, the electrostatic energy stored in the cable may be equal to or greater than the electro-magnetic energy stored in the ether surrounding the cable by the current flowing to charge it. This latter energy will be converted into electrostatic when the impressed E.M.F. of the circuit equals the back E.M.F. of the condenser, the result being that a double quantity of electricity can be forced into the condenser, and the final pressure may consequently be double the normal. In the same way opening an unloaded circuit may result in a rise of E.M.F. double the normal pressure. As a matter of fact, however, a higher pressure than double the normal has been

recorded when closing the switch of an unloaded line of 44 miles in length. This increased rise is probably due to some coincidence between the crests of the impressed waves of E.M.F. and the crests of the waves of E.M.F. of high frequency, which accompany the natural oscillations in the cable.

Reviewing the whole question, one is forced to the conclusion that circuits having appreciable capacity and self-induction should not be switched on or off, whether loaded or unloaded, suddenly. All surging currents should be avoided, and fuses should be used only when the natural reactance of the circuit is too small to prevent a dangerous rise of current.

In the next section of our paper we describe various methods of switching currents on and off gradually, which have been devised to prevent the system from being submitted to dangerous pressures.

CABLE-CHARGING APPARATUS.

The earliest cable-charging apparatus of which we have any knowledge is that installed at Deptford, Willesden, and in other places. It has been described before, and we will, therefore, only briefly refer to it now. It consists essentially in closing the circuit through high inductance, which inductance is gradually removed by manipulating a liquid resistance in series with a secondary winding on the inductance coil. An ordinary transformer can be used. Mr. G. W. Partridge informs us that it is important with this apparatus to short-circuit the primary winding as soon as the full E.M.F. is indicated by the circuit voltmeter. If this is not done, he has found that a rise of pressure 50 per cent. above the normal may occur on the circuit. This is probably due to the circuit reaching the condition of resonance. This arrangement has recentiy been objected to on account of the probability of resonant rise of pressure occurring with it, but it seems to us that as the pressure of the circuit is under observation when the apparatus is being used the danger is small. The fact that this apparatus has been in daily use at Deptford since 1892, and Mr. Partridge informs us is working perfectly satisfactorily, is, we think, good reason for regarding it with confidence.

Another method of charging is to run up a separate motor alternator on the circuit, and then to synchronise and parallel. The chief objection to this system is the time it takes to perform the operation, and the apparatus must also be somewhat complicated and costly. This system is in use in Manchester and elsewhere.

A third method is one which one of the authors worked out some years ago. It consists in using a regulating transformer of the type described in the section of this paper dealing with "Regulation." The secondary is wound to give the full E.M.F. of the circuit when the movable core is in the position of maximum effect, and the primary is excited from the main 'bus-bars. Fig. 3 shows the arrangement of connections for single-phase working. The system is equally applicable to the polyphase supply. In the figure, A_1 and A_2 are the 'bus-bars, R is the regulating transformer, C is the circuit, and B_3 is the

charging 'bus-bar. When it is desired to charge a circuit, it is plugged on to the charging bar by means of the plug P. The regulating transformer is then operated by a hand-wheel until its secondary volts equal the main 'bus-bar volts. The main switch is then closed, and the plug withdrawn. The whole operation can be effected in a few seconds, and it has the advantage of being reversible, that is to say, circuits can be gradually switched off as well as gradually switched on. It occupies a very small space, only one transformer being required for any number of circuits. As the transformer is only excited for a very short time it is safe to work at a high induction in the iron and a large current density in the copper. Messrs. Cowans have used a standard 15 kw. regulating transformer (Fig. 4) for 150 kw. charging current, the temperature rise being inappreciable after five minutes at full load. They have also been made to give, in conjunction with a step-up transformer, 60,000 volts secondary pressure.

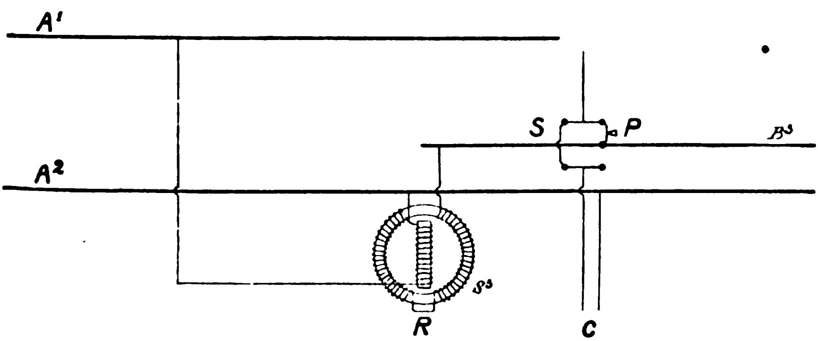


FIG. 3.

The last arrangement for cable-charging we propose to describe is a variable water resistance method. The system has been recently worked out by Messrs. Ferranti, and the apparatus is illustrated in Fig. 5.

It consists of a metal containing vessel A supported in a cast-iron case B, on and by insulators C^1, C^2, C^3. In the containing vessel are rigidly fixed two porcelain tubes D^1, D^2, these tubes being about 5 feet long by 3 inches internal diameter. Each tube contains an ebonised iron rod E, carried at its upper extremity by an insulator D. At the lower end of this rod is a piston F, upon which is fixed a metal cap G. This cap is electrically connected to the terminal H by a spiral tape conductor I. The piston F fits into a well at the bottom of the containing vessel, which is filled with mercury. A gauge glass J enables the height of the water to be seen through a glass window in the outer case. The height of this water is normally kept about 3 feet above the bottom of the containing vessel, and the total upward travel of the rods is 2 ft. 10 in. The apparatus illustrated is intended for use

in connection with a two-phase system, one tank being provided for each phase. The ebonised rods are carried at the extremities of a connecting crosshead. The weights K tend to lift the crosshead, but this is prevented when the rods are in the lowest position by a catch controlled by an electric magnet L.

The method in which this charging gear is inserted in circuit with the feeders is practically similar to that shown in Fig. 2. To charge a feeder the catch is released, thus allowing the balance weights to lift the crosshead and so increase the length of the column

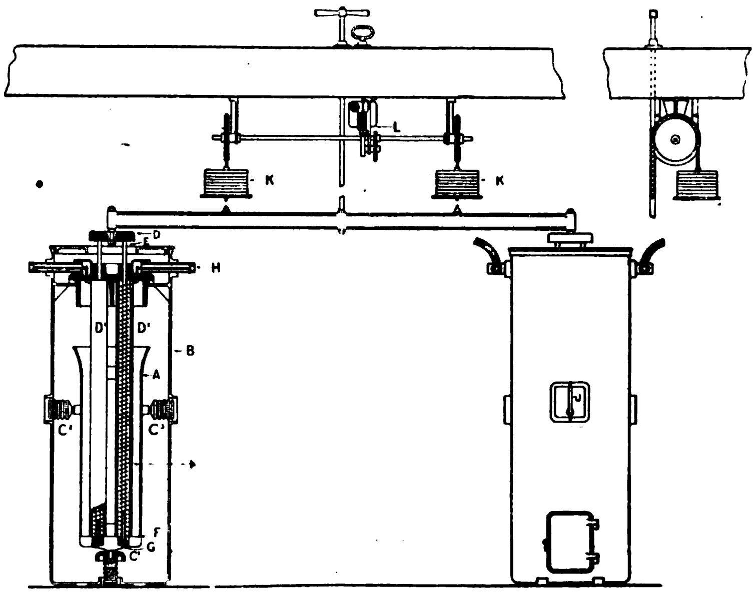


FIG. 5.

of water to its maximum. The feeder switch is set at half-cock, thereby connecting the feeder to a small auxiliary 'bus-bar corresponding to the synchroniser bar in the "Ferranti" standard generator switch-gear. This bar is connected to one terminal of the cable-charging device. The other terminal is connected to the main 'bus-bar through a fuse and switch on a special feeder-charging-panel. The water resistance in series with the feeder is then gradually reduced by pushing down the crosshead to its extreme limit of travel. This is done by a length of rod terminating in a handle above the switchboard gallery. When all the resistance has been cut out the catch comes into operation and holds the crosshead down; the feeder switch is then finally closed. A hand release to the catch is provided to enable the apparatus to be used for charging another cable in a similar manner. To discharge a feeder the rods are pushed down

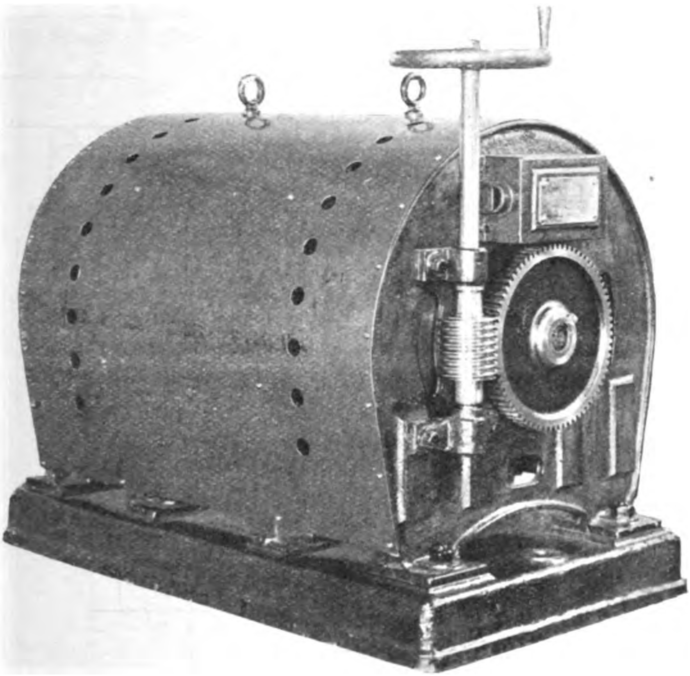


FIG. 4.

to their lowest position (if they have not previously been left thus), and the feeder switch is pulled out on to the second contact. In this position the magnetic release trips the catch and thus allows the weight to descend and gradually increase the length of the column of water. The operation is finally completed by opening the oil break switches on the feeder charging panel. A plug switch is provided for isolating purposes only.

Duplication of Transmission Lines.

Without question every high-potential line should be duplicated. The Board of Trade in general insists upon this being done. These

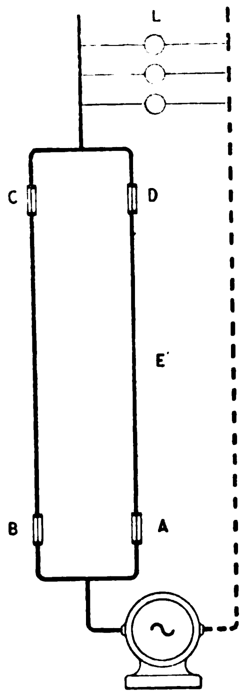


Fig. 6

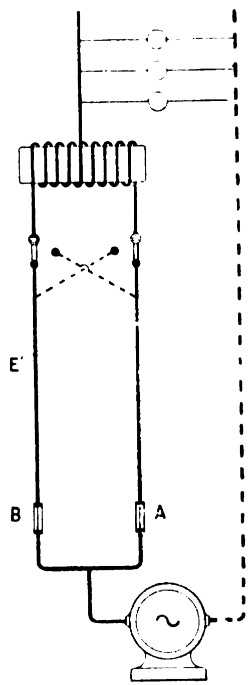


Fig. 7.

duplicate lines should be run in separate ducts if laid underground, and on separate poles if overhead. It is not safe to work on a high-potential line while any of the wires on the cross arms are alive.

Some engineers have held the view that to ensure continuity of supply one of the lines should be kept as a spare—that is to say, the duplicate line should not be coupled in parallel.

When it is remembered that the line losses are proportional to the *square of the* current, it will be clear that the losses in transmission will

be four times as great if the spare main is kept idle. It will be evident, therefore, that the difficulties arising through coupling the mains in parallel must be very serious to induce engineers to increase their line losses fourfold rather than face these difficulties. A system cannot be considered efficiently duplicated unless arrangements are made for reliably disconnecting the short-circuited feeder from the system, leaving the supply maintained through the healthy feeder. Many attempts have been made to do this by inserting fuses at each end of both of the feeders. These fuses should evidently all be of the same capacity, as it cannot be foreseen that any one of these will be required to carry more or less than the other. Now, should a fault occur at E′, Fig. 6, fuse A will certainly be blown first. Current will then feed back through fuses B, C, D, but B, C have now to carry the whole of the current to the load L, in addition to the current necessary to blow the fuse D; as a consequence, fuse B or C is almost certain to be blown before fuse D, and a complete interruption of the supply will occur.

This interruption would not be so serious if the attendants at the generating station, and at the distributing centre, were able to at once disconnect the faulty main and continue the supply through the healthy main; but this they cannot do because they have nothing to indicate, without testing, which main has failed. As a consequence considerable time must elapse before the supply can be continued. When the line has ultimately been cleared, if synchronous motors are used in the converter stations these will all have to be run up and paralleled, and after this has been done, if all consumers have left their motors connected to the supply, a very heavy starting current will be required to get them away. In connection with several of the power schemes in the States consumers have been requested to disconnect their motors whenever an interruption to the supply occurs and to keep them off until the supply is recommenced, and then switch them on one by one.

The loss arising through the stoppage of many hundreds of motors for only a quarter of an hour is liable to be extremely heavy.

It is not then surprising that some engineers have considered it advisable to keep one of their transmission lines purely as a spare, so that the attendant at each end of the line can switch over from the faulty main to the spare main. This can sometimes be done sufficiently quickly to prevent any appreciable slowing down of induction motors and rotary converters.

A perfect duplicate transmission line should, we think, fulfil the following specification:—

(*a*) It should be possible, without increasing the risk of an interruption to the supply, to keep both lines in continual service, thereby reducing the line losses by 75 per cent.

(*b*) A fault on either line should have no effect on the remaining line, other than causing it to carry the whole load previously borne by the two.

(*c*) The supply to the distributing centre should not be even momentarily interrupted, as the shortest interruption is sufficient to cause synchronous motors to fall out of step.

A system devised some years ago by one of the authors which is in use in this country and in the States is to place return current, or discriminating cut-outs, at the distributing end of the transmission lines in place of the fuses C and D, Fig. 6.

This system meets the requirements of the case for high-resistance faults, but difficulties occur with low-resistance alternating-current faults.

Another defect which the above arrangement shares with a system protected by fuses alone is that immediately the fuse on the power-station side of the fault has blown, the whole of the current to the short will be thrown upon the healthy main, and if the cut-out or fuse at the distributing end of the faulty main operates, when it will be required to break this heavy short-circuit current with consequent line disturbance.

A simple device for the protection of duplicate mains is illustrated in Fig. 7.

It will be seen that the feeders are connected together at the distributing end by a choking coil, wound entirely in one direction. The supply to the load is taken off from the centre of this coil.

Under normal conditions, the current divides equally between the two feeders and the two halves of the choking coil, but the current from one feeder flows round the iron in one direction, and from the other feeder in the opposite direction, and as a consequence the winding is perfectly non-inductive, and the only resistance to the flow of current is that due to the ohmic resistance of the circuit.

Should a fault now occur at say E′ the fuse B will be blown, and the current will tend to feed back towards the short through the choking coil at the distributing end of the lines. This current will, however, be entirely in one direction, and the choking coil will, in consequence, become a highly inductive resistance, and will prevent a heavy current flowing to the short. The supply will not be even momentarily interrupted, but it will be maintained at half-pressure only, so long as the faulty main is connected to one side of the choking coil. The attendant in the distributing station will, however, be able to instantly see from the instruments which feeder has broken down, and no time need be lost in switching this off and leaving the supply maintained through the healthy feeder alone.

It will be evident that when one feeder only is left connected, the choking coil must either be short-circuited or must be so connected up to the one main as to cause the current to divide equally between its two halves. The simple two-way switch shown in Fig. 7 may be used for this purpose.

No automatic cut-outs of any description are necessary with this device, as even if the attendant is not at hand to instantly operate the switches no further damage will result to the system, and the supply will be maintained at half-pressure. If, however, it were possible to automatically operate the two-way switch at the distributing end of the lines there would certainly be some advantage in doing so even in cases where an attendant is normally in charge, and for small sub-stations in which there are no attendants, some automatic device would certainly

make the arrangement more complete. It is believed that the automatic release shown in Fig. 8 will prove to be perfectly reliable, and it is so simple and free from delicate and moving parts that it appears scarcely possible that it should get out of order.

Two small transformers are connected up as shown in the diagram between the two high-tension feeders. Under normal conditions the direction of the current in these windings will be as indicated by the arrow-heads; and this magnetising force will tend to cause a flux to

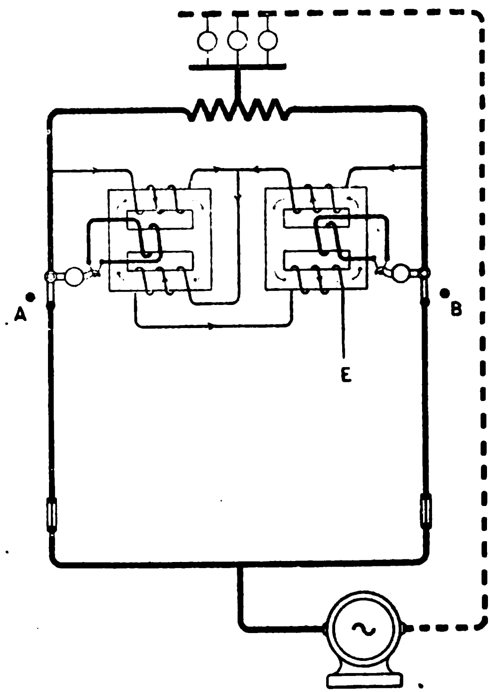


Fig. 8.

circulate round the outer limbs of the transformer. There will obviously be no tendency for magnetic flux to flow through the centre limb upon which the secondary winding connected across the copper fuse wire supporting the weighted switch is wound. Should, however, one of the feeders break down, the two small transformers will be fed from the remaining healthy main only, and the direction of the current and resulting flux will be as shown in Fig. 9. It will be seen that the flux in the transformer controlling the switch on the healthy main remains as before, but in the other transformer the flux will be diverted through the centre limb, and a heavy current will be induced in the copper fuse supporting the weighted switch on the faulty main, thus causing this to

open and instantly disconnect the fault, leaving the supply maintained at normal pressure through the healthy main.

In Figs. 8 and 9, the controlling transformers are connected to earth at E, and the contacts A and B are connected respectively to the opposite feeders.

The system described above, which has been recently shown in practical operation to a number of engineers at Hastings, appears to us to fulfil the three requirements specified above at a reasonable cost.

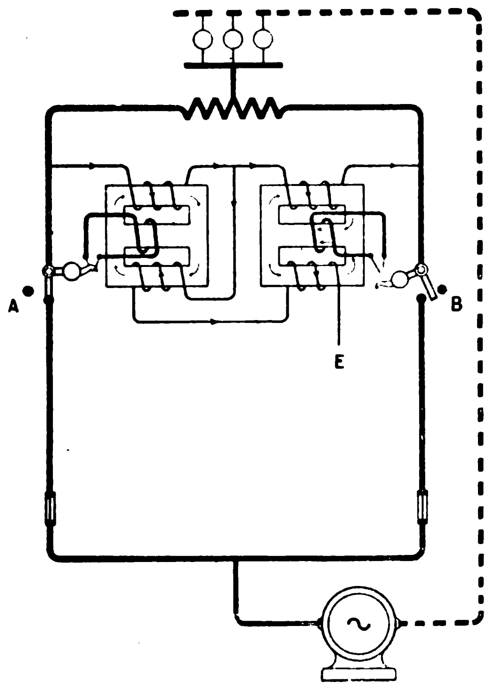


FIG. 9.

Current Direction Indicator.—A modification of the discriminating transformer referred to above may be used with alternating-current generators connected in parallel for the purpose of indicating whether a generator is feeding the 'bus-bars or receiving current therefrom. Without some device of this description the attendant has nothing to indicate, in the event of a failure, which generator to switch out, as the fault will cause the ammeters on both the defective machine and on the remaining healthy machines to indicate an excess current. Serious interruptions have resulted from this cause.

The discriminating transformer is in this case connected up as shown in Fig. 10. Red and green lamps, A and B, are connected

respectively across the terminals of two secondary windings. A primary winding C is connected directly across the 'bus-bars or across any secondary circuit excited from the main 'bus-bars. The effect of this primary winding is to induce a magnetic flux in the core of the transformer in the direction indicated by the thin arrows. A second primary winding D consists of one or two turns inserted in series with the generator connections. The effect of a generating current in this winding is to induce a flux in the direction shown by the thick arrows. It will be seen that the fluxes due to the two primaries oppose each

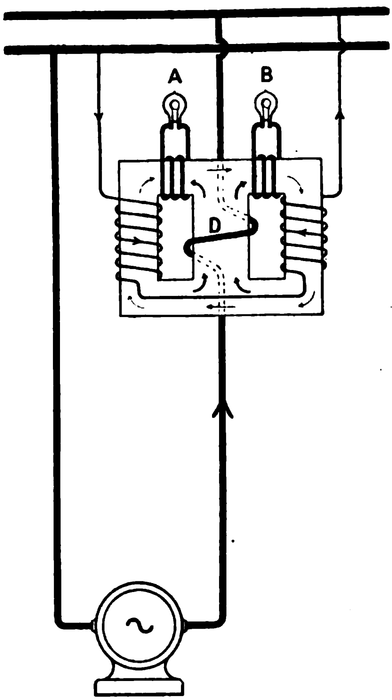


FIG. 10.

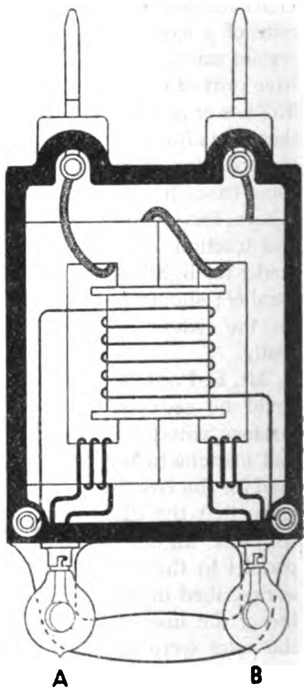


FIG 11.

other through the secondary connected to the red lamp, and assist each other to light the green lamp. Should the generator fail, the direction of the series flux relatively to the shunt flux will be reversed, and as a consequence the green lamp will be extinguished and the red lamp lighted. This current-direction indicator has also proved of great assistance in getting machines out of parallel.

Fig. 11 shows the current-direction indicator fitted into the fuse pot of a Ferranti switchboard. This forms a simple arrangement in cases where fuses are not required in the generator panels.

We trust that the importance of the subject will be accepted as an

excuse for the length of this paper. We are hopeful that, by co-operation between all who are interested, manufacturers, consulting engineers, and capitalists, Great Britain may, in due course, take the position in Long-distance Power Transmission she has held for so long in Long-distance Telegraphy.

We wish to express our thanks to Messrs. Ferranti, Mr. F. Pooley, Mr. W. B. Esson, and Mr. Preece, all of whom have kindly furnished useful particulars.

Mr. H. C. GUNTON did not agree with the authors on the earthing of the neutral point of the three-phase system. A case had recently come under his notice in which a man had received a shock from one of the arms of a 6,000-volt system and had recovered from the shock. This system was not earthed; had it been so, undoubtedly the shock would have proved fatal, whereas he had only received a condenser discharge. The use of a motor-alternator for charging the feeders, and discharging them, was found very satisfactory, and the operation could be quickly performed. There should always be duplicate mains (feeders), but in some cases it was not advisable that they should be run in parallel. Where, for instance, the mains fed a sub-station from which lighting and traction were supplied, it would be found advisable to use one feeder for lighting and one for traction, instead of running the two in parallel; should one break down, the other could, of course, be used for the whole supply. Double duplicate mains would be very costly. Mr. Gunton.

Mr. F. POOLEY thought the capital cost of some power companies could be reduced by having portable transforming apparatus. For instance, where the supply included seaside towns with a summer peak, and manufacturing towns with a winter peak, the apparatus could be used for the two cases. The cost of cables could be reduced if it were taken that the dielectric did not require to be proportionately thick with the higher voltages. He thought that the barbed wire run parallel to the transmission lines to overcome the effects of lightning, as described in the paper, would increase the capacity. The length of life of the line could be covered by a 5 per cent. depreciation fund, if the poles were well creosoted. The cost of aluminium wires worked out about the same as copper, but the poles could not be distanced to any appreciably greater extent with the former. Mr. Pooley.

Mr. H. W. CLOTHIER said that the authors had dealt with several important features of alternating-current working. He considered that the flare switch for alternating-current working was obsolete. The magnetic blow-out system in continuous-current working was bad, owing to the tendency of the voltage to rise on the sudden breaking of the circuit. A question of vital importance was that of cable charging; there was much obscurity, and though there were numerous calculations and theories of what happened when a high potential was suddenly switched on or off a cable, there were few actual records of results. In America and in several British stations no "charging" appliances were used, and yet they had heard little of disastrous effects. Perhaps they were paying too much attention to the subject? Mr. Clothier.

Mr. Clothier. He would like to know what were the limits before "cable charging" became advisable.

Mr. Nisbett. Mr. G. H. NISBETT was sorry that the first part of the paper consisted of an appreciation of overhead as against underground cables. He thought that what was often said of overhead wires must be taken with a grain of salt. A number of objections, more or less reasonable, were cited against overhead mains, and he concluded that overhead wires were a relic of barbarism. It was unfortunate that cable-makers did not know to what stress their cables would be subjected. In one instance, where the cables had to carry current at a pressure of 5,000 volts, it was found they were subjected to a pressure of from 12,000 to 13,000 volts every time they were switched on or off. Engineers should specify a maximum rise of voltage, and see that this was kept to; also, he would emphasise the importance of the alternator curve being as nearly a sine curve as possible. He agreed with the authors that it was advantageous to earth the neutral point of the three-phase system; by this means a saving of 15 per cent. could be made on the cost of the cables.

Mr. Coubrough. Mr. A. C. COUBROUGH noted with surprise that the authors thought the single-phase alternating-current system could come into use again. The only chance for that system would be by the adoption of series-wound single-phase motors, and then probably a two-phase generating system would be adopted. The only sound reason for adopting a two-phase system was the possibility of using mains that had served for a single-phase system. Frequencies were steadying down, 60 cycles being now the upper limit, and the lower limits were fixed by the requirements for satisfactory lighting; probably 40 cycles would be found best for all-round purposes. Generators, when taken in conjunction with their driving motor, varied very little in cost with different frequencies, and the advantages of smaller capacity, less charging current and lower impedance drop, were with the lower frequencies. Both arc and incandescent lighting were suitable at 40 cycles. More knowledge was wanted of the various phenomena accompanying the disruption of high-potential alternating-current circuits; he would suggest that a possible combination of an oscillograph and a cinematograph camera might be useful.

Mr. Kemp. Mr. J. P. KEMP did not agree with the earthing of the neutral point of the three-phase system; this would necessitate more insulation on the generators, and would reduce the safety-factor of the system. Cases in which men touched one of the arms of H.T. non-earthed three-phase combinations, and were not killed, were evidenced as proof of this. A method of charging cables by means of a step-up transformer and motor alternator, which had been in operation nine months, was very satisfactory. The Board of Trade required tests to be made at 1½ times the working pressure, and the "charging" plant had been most useful in this respect. The time taken to charge up a feeder was about forty-five seconds.

Messrs. Cowan and Andrews. Messrs. COWAN and ANDREWS replied very briefly to the points raised. From the statements made in the discussion, Mr. Cowan was prepared to modify his view on the earthing of the neutral point of the

Messrs. Cowan and Andrews.

three-phase system when the pressure and condenser capacity of the cables were within moderately safe limits, as appeared to be the case in Manchester. There was always the danger, however, that a fault might be allowed to remain some time unrepaired when the neutral was not earthed, and in this case the danger was increased by not earthing. The increased capacity due to barbed wire for protection of transmission lines from lightning, was said to be inappreciable. He thought the question of pressure rise in cables must be a matter for experiment. He was at a loss to understand why in some cases in America the frequency had been raised instead of lowered. Mr. Andrews thought that where a sub-station supplied current for both lighting and traction, duplicate mains for each should certainly be used.

NOTICE.

1. The Institution's Library is open to members of all Scientific Bodies, and (on application to the Secretary) to the Public generally.

2. The Library is open (except from the 14th August to the 16th September) daily between the hours of 10.0 a.m. and 6.30 p.m., except on Saturdays, when it closes at 2.0 p.m.

An Index, compiled by the late Librarian, to the first ten volumes of the Journal (years 1872-81), and an Index, compiled under the direction of the late Secretary, to the second ten volumes (years 1882-91), can be had on application to the Secretary, or to Messrs. E. and F. N. Spon, Ltd., 125, Strand, W.C. Price Two Shillings and Sixpence each.

A further Index, compiled by the Secretary, for the third ten volumes (years 1892–1901) is now ready, price Two Shillings and Sixpence, and may be had either from the Secretary or from Messrs. Spon.

Publishers' Cases for binding Vols. 30 and 31 of the Journal can now be had from the Secretary or from Messrs. Spon, price 1s. 6d. each.

JOURNAL

OF THE

Institution of Electrical Engineers.

Founded 1871. *Incorporated* 1883.

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The Three Hundred and Ninety-fourth Ordinary General Meeting of the Institution was held at the Society of Arts, John Street, Adelphi, W.C., on Thursday evening, May 7th, 1903—Mr. ROBERT K. GRAY, President, in the chair.

The minutes of the Ordinary General Meeting of April 30th, 1903, were, by permission of the meeting, taken as read, and signed by the President.

The names of new candidates for election into the Institution were taken as read, and it was ordered that the names be suspended in the Library.

The following list of transfers was published as having been approved by the Council:—

From the class of Associates to that of Associate Members—

John William Gibson. | Jas. Noel C. Holroyde.
Joseph P. McMahon.

Messrs. C. W. Barnes and R. Tervet were appointed scrutineers of the ballot for the election of new members.

Donations to the *Building Fund* were announced as having been received since the last meeting from Messrs. W. S. Entwistle and E. M. Malek; and to the *Benevolent Fund* from Mr. W. S. Entwistle, to all of whom the thanks of the meeting were duly accorded.

The following papers were then read:—

APPLICATIONS OF ELECTRICITY IN ENGINEERING AND SHIPBUILDING WORKS.

By A. D. WILLIAMSON, Member.

So much has been written on the subject of electric driving that it is difficult to avoid repetition. The author will confine himself to facts within his own experience, and not attempt to introduce published results for which he is not responsible.

The plant which will be described in this paper has been erected in the works of Messrs. Vickers, Sons and Maxim, Limited, and amounts in the aggregate to about 22,500 B.H.P. of generators and motors.

In 1896 Messrs. Vickers were commencing some considerable extensions to their works, partly by building a number of new shops, and partly by acquiring a shipyard at Barrow-in-Furness and Small Gun works at Erith, resulting in an increase in the number of employés from about 3,000 to nearly 20,000 during the four or five years following 1896. The great convenience of the motor-driving system soon became apparent in connection with the rapid extensions. Generating plant was ordered well in advance of actual requirements, and the speed at which new shops were erected and started was limited only by the time taken to deliver the structural steel work and machines. To quote one instance of this, the South Gun Shop, now covering a ground space 660 feet by 200 feet, was built in a series of seven instalments, each complete and working as soon as it was roofed over, movable corrugated iron ends being erected to keep the weather out. The whole shop now forms one of the finest machine shops in the world, and to all appearances might have been built complete at one operation.

The first power-house was situated fairly centrally, and contained four direct-driven sets of 160 k.w. shunt dynamos and 250 B.H.P. compound non-condensing engines by Siemens and Belliss respectively. The original intention was to use the current chiefly for cranes and special armour-plate grinding machines which were difficult to drive otherwise than by motors. At the same time, however, a new gun shop was being built, and the opportunity was taken to apply motors, one to each of the machines, most of which were large and required from 5 to 10 H.P. to drive them.

The success of the electric driving system under all the conditions in which it was tried determined the directors to apply it to all the extension work and, as opportunity occurred, to replace the less efficient isolated steam plants.

Then, the first 1,000 H.P. power-house being loaded to its full capacity, a larger power-house was built, on the south side of the works, having a capacity of 1,325 k.w. As much ground was given for a site as could be spared, and it was thought that the two power-houses together would be quite large enough for the whole of the works when all extensions were completed.

Later, however, it was found necessary again to increase the size of the works, and this, added to the adoption of the Vickers high-speed tool steel and the additional power taken by the machines in consequence, rendered a third station necessary, containing one 350 k.w. set and two 200 k.w. sets.

The total plant capacity at the Sheffield works is therefore 2,800 k.w., and the details of the three sets of plant are shown in the following table :—

1. *North Power-house—640 k.w.*
   Four engines, 250 B.H.P. each, compound non-condensing, 360 r.p.m.

Four dynamos, 220 volts, shunt, bi-polar Siemens.

Boilers.—Two Lancashire, two marine type, 160 lbs, fitted with Ellis & Eaves' induced draught and Bennis stokers.

Feed heater, Berryman; temperature of feed about 200° F.

2. *South Power-house*—1,325 *k.w.*

Four Engines.—Three each 480 B.H.P. tandem compound condensing, Belliss enclosed type, three cranks, speed 300 r.p.m. with 25 per cent. overload capacity.

One 530 B.H.P. triple expansion Belliss enclosed condensing engine, speed 340 r.p.m. with 20 per cent. overload capacity.

Four Dynamos.—Three each 325 k.w., shunt-wound, 220 volts, 6 poles, British Thomson Houston Co.

One 350 k.w., 8-pole shunt, 340 r.p.m., by Vickers, Sons, and Maxim, Ltd.

Boilers.—Six Babcock and Wilcox, each evaporating 6,000 lbs. of water per hour, with superheaters giving about 40° F. superheat measured at the engine separators, 160 lbs. pressure.

The stokers are of the chain grate type, driven by 5 H.P. motor.

Economiser.—One Green's Economiser, 288 tubes, driven by a 1½ B.H.P. motor, giving an average feed temperature of 260° F.

Condensers.—Three Wheeler Admiralty type, connected to a common exhaust main so that any one or all may be used as required.

Feed Pumps.—Weirs.

Oil Filters.—Harris.

Steam Pipes.—Steel, weldless. A complete duplicate system of pipes, each main being connected to each engine and each boiler, allowing repairs to be made on the idle main while the plant is at work.

Pipe Covering.—Magnesia sectional.

Cooling water for condensers is pumped from the River Don by a vertical turbine pump, driven by a 5 H.P. motor.

3. *West Power-house*—750 *k.w.*

Similar in general design to the others, but containing—

One 350 k.w. Vickers dynamo, 220 volts, 340 r.p.m.

One Belliss 530 B.H.P. triple expansion engine.

Two Bruce Peebles 200 k.w., 220-volt generators.

Two Sissons compound engines, by Markham and Co., Ltd., 350 r.p.m.

Lancashire boilers, 7′ 6″ × 28′.

One Schmidt separately fired superheater, giving about 250° F. superheat: Not yet started at time of writing.

Two watertube boilers are shortly to be put down, each to evaporate 12,000 lbs. of water per hour.

4. *Erith.* In 1898 the works of the Maxim Nordenfeldt Co. were purchased, and the old system of belt driving from one main engine was replaced by electric power. A power-house was built containing 600 k.w.

Four Belliss and British Thomson Houston sets, each 150 k.w. and 250 B.H.P., 220 volts, 360 r.p.m, with Wheeler condensers and multitubular boilers, 160 lbs. pressure.

As the works were at this time undergoing alterations and being considerably extended, the convenience of motor driving was fully appreciated.

Barrow. In 1897 the Naval Construction and Armaments Co. was purchased, and the large works at Barrow-in-Furness were thoroughly reorganised and extended, the number of men employed growing from 5,000 to 10,000 within three years from the time of acquiring the works. The Barrow works presented a very fine opportunity for applying electric power, and during the first year between 50 and 60 steam engines were taken out with over a mile of steam pipes.

It may be mentioned here that the change from steam engines to motors was made without in any way stopping the work. The change was made quickly and without inconvenience—in fact it was half done when the author was asked to state when the alterations were to *commence*, as much stoppage of work was expected.

5. The power-house on the *Shipyard* side contains the following—750 k.w. :—

Five 250 B.H.P. Mirrlees Watson compound single-acting non-condensing engines.

Five 150 k.w. British Thomson Houston shunt-wound, 6-pole, 220-volt generators.

Six 30 ft. × 8 ft. Lancashire boilers, 160 lbs.

One Berryman heater.

Twelve months saw this plant fully loaded, and it was decided to put down a larger plant on the engine works side, as the engine department had already become large users of the current for all their extensions.

6. The *Engine Works Power-house* contains space for five sets, four of which are installed—

Four Belliss triple-expansion engines each 700 B.H.P., 300 r.p.m.

Three 500 k.w. British Thomson Houston Co. 12-pole, 220-volt shunt generators.

One 500 k.w. Vickers, Sons and Maxim 12-pole, 220-volt shunt generator.

One switchboard with 4 generator panels and 32 feeder panels.

Ten Lancashire boilers, 30 ft. by 8 ft., 180 lbs. working pressure (8 in use at present).

Two Green's economisers, each 480 tubes, driven by 2½ H.P. motors.

Stokers—Bennis automatic, driven by a 10 H.P. motor (also drives coal elevator).

Coal Conveyor.—Bennis, driven by a 10 H.P. motor.

Ash Elevator and Motor.—Driven by a 5 H.P. motor.

Four Klein steam-driven sets of air and circulating pumps.

Two Klein cooling towers.

Two Klein jet condensers.

The two power-houses are connected in parallel, a system which is adopted in the other works where there are two or more stations. This plan enables one station to assist the other during temporary heavy loads, and permits of either being shut down at times of light load. Recording wattmeters are fitted in each dynamo circuit, and outputs are recorded on log sheets for the purpose of checking costs.

There are three other works of the Company using electric power, as follows :—

7. *North Kent Works.* 180 H.P. 220 volts.

8. *Wolseley Tool and Motor Car Works.* 350 H.P., 220 volts.

9. *Electric and Ordnance Accessories Company.* 560 H.P., 110 volts. Making a total plant capacity of 1,180 B.H.P. or 786 k.w. for these three works.

The author does not think it necessary to go further into details of the generating plant, as it is all of a type familiar to the members of the Institution and does not call for special description.

Reason for Adopting 220 Volts.

In 1895, when the choice was made, 220 volts represented advanced practice, as incandescent lamps had only been for a short time on the market for that pressure. No doubt a higher pressure would have offered some advantages in the Sheffield and Barrow works on account of the distances, but the difference between 220 and 250 is not really very important. With 440 volts one must give up the idea of using single glow-lamps unless the three-wire system is adopted.

It would be interesting, in the discussion, to hear the views of engineers as to the suitability of three-wire distribution with 440 volts across the outers, taking motors of 5 H.P. and upwards from the 440-volt mains, as well as all crane motors and others of intermittent loading. Small motors with steady loads, as well as arc and glow lamps, would be connected between the middle and outer wires. With careful arrangement the system should do well in large works, and it would have the advantage of giving variable speed-motors double the range they would have on the ordinary two-wire system.

It may be thought curious that shunt generators are used in all cases, as many power-stations have compound-wound generators. In practice the author has found that with a fairly large generating plant shunt generators are perfectly satisfactory, the pressure on the lamps is quite steady. By the use of shunt machines the switchboard gear is slightly simplified. If all the work had to be done again with a full knowledge of the ultimate demand for power, it is probable that the

only differences would be in the direction of raising the voltage of supply to 440, using three-wire distribution, and certainly making use of the larger sizes of plant, each unit being 750 or 1,000 k.w. capacity.

The practice of installing small sets as well as large ones, which is common and justifiable in lighting-stations, does not appear to possess any advantages for heavy works driving, as the loads are fairly uniform and of known duration. If the size of unit is chosen with due regard to the ultimate plant capacity, allowing the standby set to bear a reasonable proportion of the whole—say 20 per cent.—it is far better to have all the units alike, with a full set of interchangeable spare parts.

Cost of Production.

The systematic recording of all costs, properly subdivided, is of the utmost importance. The weekly returns, when properly kept, are sensitive indications of the state of the plant and also of the care shown by the engine and boiler staff. Although the costs as shown in the following tables are not as low as some which have been published recently, they are of interest as representing the actual figures taken from the books of the Works Cost Department. They are not made out by the Electrical Department for show purposes, nor are they the result of a week's test under exceptional conditions. They include Sundays, holidays, and other "unprofitable" times from a station engineer's point of view.

Summary of Generating Costs (One Year).

Power House.	Present Plant Capacity	Annual Output.	Fuel per Ton.	Works Costs per Unit.	Total Cost, per Unit.
	K.W.		s. d.		
(*a*) Sheffield, North	640	2,106,340	9 8½	·579d.	·716d.
(*b*) Sheffield, South	1,325	2,610,620	7 2½	·469d.	·675d.
(*c*) Sheffield, West	750	Not long enough in operation for costs.			
(*d*) Erith	600	1,430,500	20 0	1·1d. (about)	
(*e*) Barrow Shipyard... ...	750	644,500	17 0	1·3d. (about)	
(*f*) „ Engine Works	2,000	3,504,435	11 6	·77d.	·97d.
(*g*) Electric and Ordnance Accessories Co. (Dowson Gas plant)	375	364,000	19 10	·55d.	Fuel and wages only.

Total Output (including smaller works) = 11,000,000 units per annum.

Notes.

(*a*) Fully loaded.

(*b*) Not fully loaded; the plant capacity during the period of test was only 975 k.w.; the fourth set has only been put down recently. This station can easily turn out 4,000,000 units annually.

(*d*) Includes pumping all works' water with steam from these boilers.

(*e*) Comparatively lightly loaded, and includes steam supplied to a hydraulic plant.

(*f*) The building, pipes, condensers, and cooling towers are complete, and the plant capacity was only 1,500 k.w. during the year of test, while the power-house will accommodate 2,500 k.w.

Charging the proper proportion of the final capital cost against the present plant for the year, the interest and depreciation amount to ·2d., making total cost = ·97d. per unit.

(*g*) The works having been recently acquired, further information is not available.

CAPITAL OUTLAY ON PLANT AND BUILDINGS (VARIOUS WORKS).

	£	s.	d.	
Sheffield, North	20	10	0	per killowatt.
Sheffield, South	25	16	0	„ „
Erith	22	10	0	„ „
Barrow Shipyard	24	3	0	„ „
Barrow Engine Works	26	10	0	„ „
Electric and Ordnance Company	26	5	0	„ „

The most interesting figures are those relating to the Sheffield works, and an analysis of the cost is given below :—

ITEM.	Power House. North.	Power House. South.
Coal	·313	·255
Water	·046	·016
Wages and Supervision	·102	·101
Stores	·017	·016
Repairs	·101	·081
Works cost ...	·579d.	·469d.
Taxes	·027	·026
Share of Works Railway, Carting Coal and Ashes, Boiler Insurance, Employer's Compensation, etc.	·004	·004
Interest and Depreciation	·106	·177
Total Cost per Unit	·716d.	·675d.

The difference in the costs is due partly to the variation in the price of coal according to the locality, and partly to the nature of the load factor.

The Sheffield works possess the best load, lasting through the entire day and night (day load, 5,150 amperes; night load, 4,500 amperes). This refers chiefly to such work as steel melting, armour-plate and gun work, which must go on continuously. The other works make less use of night work, although a good deal is done at Barrow and Erith at times.

The amount of standby plant is determined by the number of working hours. In the case of a railway wagon shop for which the author acted as consulting engineer, no spare plant was put down, nine

hours being the usual working day. These hours of working permitted all repairs and repacking of the engine to be done during the stopping-time, and no need of spare plant has ever been felt. The usual practice is to allow 25 per cent. of standby plant when all the sets are installed.

It is interesting to compare the results of the north and south power-houses at the Sheffield works. Both work on exactly similar loads, in fact they are connected to a common network; one is condensing and has economisers in the flue, the other is non-condensing and has exhaust steam feed-heaters. The non-condensing station has sets only half the size of the condensing station, and there is a difference in the cost per unit of about $\frac{1}{10}$d. in favour of the condensing station accounted for in coal and water alone.

Finally, before leaving the subject of generating plant, the author would like to state that his experience of high-speed vertical engines running under the severe conditions of continuous heavy loads has been perfectly satisfactory. The cylinder liners of some of the engines have been carefully gauged after five years' work, and show practically no wear.

Distribution Mains and Wiring.

In almost every case the main cables are overhead, on insulators carried partly by posts and partly by the buildings. A light insulation is used to avoid short-circuits where wires come accidentally into contact, blown by the wind, as well as for the protection of telephone and other bare wires. A few underground cables have been used, but the ground in the steel works is tunnelled by flues carrying hot furnace gas, and it is not, therefore, often found possible to use underground mains. A lead-covered concentric cable, 220 yards in length, carries current to a pumping station at the riverside through a tunnel, which is often filled with water in rainy times. The motors in the pumping station are of 60 B.H.P. capacity.

Motors.

It must be owned that most of the success of electric driving has been due to the great improvements which have recently been made in manufacturing motors. Certainly there are still numbers of the old motors in use which were put down six years or more ago, but if the old smooth-core armatures had not given way to the more robust tramway type of armature, many of the applications of electric driving could not have been made. The motor and starter of six or seven years ago were things to be handled with care, and hardly to be trusted to an ordinary workman to start. Now, Messrs. Vickers have over 1,300 motors in use, all of which are started and controlled by the workmen attached to the machines or cranes, and, in spite of the very rough usage still common in the shops, it is wonderful how well the modern machines take care of themselves.

At the outset a strong effort was made to cut down the number of sizes of motors, and also to secure interchangeability of the armatures

and other parts likely to require replacement. Once decided upon, a type of motor was kept as a standard until a sufficient reason caused it to be superseded. For instance, perhaps twenty or thirty motors of 10 H.P. were ordered, with a spare armature to fit any of them. When these motors were all used, it was considered that one spare armature might fairly be allotted to those twenty or thirty motors, and if a better type of motor of that size were available there was no objection to adopting it, and having a spare armature for the new type.

The following list gives particulars of the standard motors and their speeds :—

B.H.P.	Type.	Speed.
1	Semi-enclosed	1,200
2½	" "	800
5	" "	600
5	Enclosed	600
5	Semi-enclosed	Variable—300 to 900
10	" "	600
10	Enclosed	600
10	Semi-enclosed	Variable—300 to 900
15	" "	600
20	" "	600
25	" "	600
25	" "	Variable—300 to 900
30	" "	500
40	" "	500
50	" "	500
75	" "	400

Of course there are a certain number of other types, on cranes and small portable tools, but the same principle of interchangeability and few types has been a ruling factor throughout.

These speeds are lower than many makers call their standards, but when one considers that in nearly every application the speed has to be reduced to quite a small proportion of the original speed at the point of utilisation, it will be seen that a low initial speed is a great advantage, often counterbalancing the rather higher cost of the motor. No hard and fast rule can be made determining the size of machine which should be driven by a separate motor. At first it was decided to make 5 B.H.P. the smallest motor for a single machine, but many cases arose where it was found advantageous to put a motor of 2 or 3 H.P. on a machine which only worked intermittently.

The use of single motors has proved of great convenience in placing machines, rendering them independent of the line shaft; it also allows a free space for the travelling cranes to work in by dispensing with the network of overhead belting. As regards actual efficiency during working time there is little to choose between line shaft driving and separate motors, although the difference is in favour of the separate motor system unless the smallest motors are used. Considering a line

of ten lathes, each of 18-inch centres, driven in three alternative ways, viz.:—

(1) By one 40 B.H.P. motor and line shaft 110 ft. long.
(2) By ten 5 B.H.P. motors, constant speed, with step cones for varying speed. Belt drives.
(3) By ten 5 B.H.P. motors, variable speed, mounted on the lathe headstocks, and no belts.

The capital outlay and losses at *full load* are set out in the following table:—

	Cost of Driving Arrangements.	Loss in Shafts and Belts.	Loss in Motors.	Total Loss.
(1) 40 H.P. motor. Machines in 2 rows of 5 per row	£410	4 E.H.P.	4 E.H.P.	8 B.H.P.
(2) Ten 5 H.P. motors (constant speed)	£575	2 E.H.P.	7·5 E.H.P.	9 B.H.P.
(3) Ten 5 H.P. motors (300 to 900 speed)	£685	—	7·5 E.H.P.	7·5 B.H.P.

In the case of the 40 H.P. motor there is a fixed loss of about 4 H.P. in shaft and belts, when the shaft is running and no lathes working. With no lathes working in the cases 2 and 3 there is no consumption of energy. With five of the ten lathes working the comparison is as follows:—

	Loss in Shaft and Belts.	Loss in Motors.	Total Loss. B.H.P.
40 H.P. motor	3	3	6
Five 5 H.P. motors, constant speed	1	3·75	4·75
Five 5 H.P. motors, variable speed	—	3·75	3·75

Working conditions would be fairly represented by assuming eight out of ten machines to be in use, the remaining two having tools or work changed or set.

The choice really lies between the 40 H.P. motor and one of the two separate motor systems, and of these two the variable-speed system is certain to be preferred by any one who has had experience of its

convenience. Comparing systems 1 and 3 for working cost under average conditions, the results are approximately as follows :—

Eight lathes working out of ten—
Total loss—System 1 = $7\frac{1}{2}$ B.H.P.
" " 3 = 6 "

One B.H.P. is practically one unit at the switchboard, there is thus a saving of $1\frac{1}{2}$ units per hour, or $1\frac{1}{8}$d. per hour at ·75d. per unit. This amounts to 5s. per week of fifty-four hours, and £13 per annum. From this saving must be deducted the interest at 4 per cent. on the difference in the capital outlay, which is equal to £11 per annum, leaving the apparent balance of only £2 per annum in favour of the variable-speed motors.

This saving is the minimum, as the working conditions do not always prevail, and for every hour of overtime work with only one or two lathes working there is a large balance in favour of the small motors. As the load diminishes below half load on the large motor its efficiency falls away rapidly, while the small motors are always working at a high efficiency when working at all. The output of work is largely increased by not requiring belts to be shifted in the latter case.

The above case is not particularly favourable to variable-speed motors ; the price per unit is usually above ·75d. in works only running fifty-four hours per week. Working continuously $5\frac{1}{2}$ days per week, the nett saving would be $1\frac{1}{8}$d. × 132 = 12s. 4d. per week or £32 per annum, less £11 interest = £21 per annum, plus the large saving due to increased output and reduced power costs for overtime work.

No doubt the first cost prevents many owners of works from adopting separate motor driving, but where money can be raised at a cheap rate of interest there is little doubt that that system is the more economical one where the machines are of sufficient size to justify the use of separate motors. Unfortunately it is a common habit, when electric driving has been decided upon, for the works manager or engineer, with no special knowledge of the subject, to take the settlement of all the details on himself, with the result that many of you must have seen. Electric driving will not necessarily cheapen production in all cases, and unless it is undertaken with some knowledge and a good deal of thought, it may affect the cost of producing work adversely.

The author has had to advise in the case of some works where the conditions appeared to be most favourable to electric driving at first sight. The engine was about 40 years old, the shafts, belts, and general arrangements were as badly planned as could be, and yet, on carefully estimating the cost of conversion and probable saving, there was so small a margin that he advised the retention of the existing plant in the interests of economy. The percentage saving would have been considerable, but the coal bill and other costs were so low that the financial results would have been disappointing. For the same reason, it is only where the conditions are very favourable that electric

driving can replace the older system economically in parts of the country where coal is cheap.

The particular case referred to above was that of a small compact factory, in three stories, covering but a small ground space. The steam pipe was very short, and the losses were chiefly in the shafts and belts. As the machines were many and small, it would have been impossible to dispense with the shafts, and only the main belts from floor to floor would have been saved by motor driving. Had the works consisted of isolated shops instead of floors, the case would have been entirely favourable for electric driving.

The number and horse-power of the motors in the various works of the Vickers Company are stated in the following table, which divides them into three classes, viz.:—

(1) Motors working continuously.
(2) Motors on cranes and hauling gear.
(3) Motors performing auxiliary operations, such as travelling lathe saddles and other occasional work of very short duration.

The average current absorbed by the motors in each case is also stated, and it is a rough indication of the size of generating plant required for dealing with such a load. Of course this figure naturally varies according to the proportion of crane motors to those of steady loading, but it may be of use to engineers when considering new cases of a similar nature.

Total number of motors (all the works) = 1,311.
Total B.H.P. of motors „ „ = 12,400.

TABLE SHOWING MOTORS INSTALLED AND AVERAGE LOADS.

Works.	Shafting and Machine Motors.		Crane Motors.		Intermittent Load Motors.		B.H.P.	Average current at 220 v.	Amperes per B.H.P. of Motors at 220 v.	Ratio Constant Load Motors to Total H.P.
	No.	B.H.P.	No.	B.H.P	No.	B.H.P.	Total.			
Sheffield	299	2464	170	2683	174	657	5804	5150	·89	·425
Barrow ...	295	3388	145	1542	—	—	4930	5530	1·125	·690
Erith ...	80	862	33	216	—	—	1078	1100	1·02	·800
Wolseley	14	160	—	—	—	—	160	just	installed	1·00
North Kent	11	122	—	—	—	—	122	220	1·80	1·00
Elec & Ord (110 v.).	90	300	—	—	—	—	300	1500	2·50	1·00

GEARING.

The question of type of gearing is of great interest; few machines lend themselves to direct driving by motors of reasonable speed

without the interposition of a certain amount of gearing. Fans, saws, and some woodworking machines are practically the only cases where high speeds are required. The choice of gearing is not very wide. The types may be divided into the following classes :—

(1) Worm Gear.
(2) Spur Gear with metal wheels.
(3) Spur Gear with metal and raw-hide.
(4) Spur Gear with mortice wheels.
(5) Friction Gear.
(6) Chain Gear.
(7) Belting.

The author has tried all the above, and finds that only spur gear, chain gear and belting are of real use, except in special cases.

Worm Gearing, to be efficient, must be fitted with ball thrusts, run in oil, and must be very well made. It is expensive, but where great speed reduction is required it is useful, especially in such cases as hoists, where the work is occasional and the efficiency of minor importance.

Friction Gear is inefficient and cannot be applied for large powers.

The three classes of *Spur Gear* are all good ; the speed and permissible amount of noise determines which class should be adopted. The author places a limit of about 1,000 feet per minute for metal spur gears, beyond which the noise becomes unpleasant in ordinary machine shops. At this speed, cut gears with well-formed teeth are necessary. Raw-hide and metal can easily be used up to 2,000 feet per minute.

Belting is of course applicable to nearly all cases, the slipping being a positive advantage where heavy shocks and reversals of machines take place.

Chain Gearing has the advantage of silence and positive driving; it is most suitable for short drives. Renold chains from 5 to 80 H.P. are used in the Sheffield and Barrow works, with excellent results. Chain drives are only fit for shops which are clean and free from dust and grit, unless special steps are taken to case them in well. A common method of line shaft driving is to fix the motor to a column or wall bracket and drive the shaft by a chain, the centres of the shaft and motor being about three or four feet apart. This economises floor space, and a speed reduction of 6 to 1 is easily obtained, as the chain wheel may be considerably smaller than a belt pulley transmitting the same power.

Variable-Speed Motors.

The problem of varying the speed of motors without loss of efficiency has received a good deal of attention during the last few years, and there is now no difficulty in building motors with a range of three to one, or even more, by varying the field excitation. The limiting factor is the highest speed to which it is permissible to go from mechanical considerations, and the range and lowest speed depend on the price to which one is prepared to go. A three to one range appears to be about the most economical one for motors of fair

size, say from 250 to 750 revolutions, or 300 to 900 revolutions for motors from 5 to 30 H.P. Any reduction of speed below about 300 causes the weight and price to rise rapidly.

The author's firm is now building motors which work sparklessly with fixed brushes with a speed variation of three to one, and it is only on account of the difficulty of arranging satisfactory mechanical drives that higher maximum speeds are not used.

An application of variable-speed motors which the author believes to be novel has been recently used in the electrical manufacturing shop of Messrs. Vickers. A portable vertical planer or slotting machine is driven by a 5 B.H.P. motor with a range of speed from 300 to 900, the motor being attached direct to the machine. On the cutting stroke the motor runs at its slowest speed, and at the end of the stroke, the length of which is easily adjusted to suit the work, the motor reverses automatically. As soon as the reversal has occurred a resistance is automatically inserted in the field winding, quickly raising the speed to 900 for the return stroke. At the end of the quick return stroke, immediately before reversal, the field resistance is short-circuited, providing a strong field for reversing in, and the motor reverses and makes its slow cutting stroke, the cycle repeating itself. The insertion and removal of the field resistance necessitates a special form of switch which is provisionally protected and cannot at present be described in detail. The arrangement has been in use for some time successfully, and it is anticipated that it will be of great use in driving many types of reciprocating machines. In actual practice it is found that this method of driving is very economical and possesses advantages over the usual belt reversing drive, as the excess current at reversing can be reduced to a negligible quantity.

There are about 110 variable-speed motors in the Sheffield works driving lathes and gun-boring machines, and they do their work most satisfactorily. They were all built by the electrical department of the Company.

There is a great saving of time in such operations as parting off heavy shafts, the turner being able to follow the work as the diameter diminishes and keep his cutting speed at its maximum without having to shift his belt from step to step.

While the motors for line shaft and machine driving are almost invariably shunt-wound, there are cases where the conditions call for heavy starting currents, and compound motors or pure series motors are used. Such machines as punching and shearing machines, angle and beam cutters, and other shipyard and boiler-shop tools, have heavy flywheels, requiring large currents to accelerate them. The work is done by a temporary fall in speed of the flywheel, and the light-load current does not fall below about half the full-load current. Here series machines are excellent, a constant speed is not required, and there is always sufficient load to keep the speed from reaching a troublesome limit.

Reversing motors do not seem to be in use to the extent that their merits entitle them to, and it is a very common thing to see plate-bending rolls and straighteners driven by a motor belted to a counter-

shaft, which drives the machine by open and crossed belts. The space occupied is considerable, and the belts usually slip a good deal. There is no difficulty whatever in arranging good compact drives with reversing motors driving through spur gearing. In the Barrow Shipyard there are several rolls driven thus, by 45 and 30 H.P. motors. Liquid controllers are used for these, and in the Sheffield works some rolls for bending 3-inch gun shields are driven by 22 H.P. tramway motors with standard tramway controllers.

Some of the most interesting examples of electrically driven machines are described in the following table of tests, and although many of them may be very similar to results published in other papers, the author hopes that, taken in bulk, they may be of use to engineers as a table of reference. The machines are divided into 11 classes as follows:—

1. Lathes and Boring Machines.
2. Planing Machines.
3. Slotting Machines.
4. Shipyard Plate Machines (Punchers, Shears, Countersinks, Angle cutters, Rolls).
5. Drilling Machines.
6. Pumps.
7. Cranes.
8. Saws for Metal.
9. Wood-working Machines.
10. Special Machines.
11. Fans and Blowers.

The method of setting out the tests may seem cumbersome, but unless the conditions are clearly stated and the method of driving described in some detail, the results are of little use.

Class I.—Lathes and Boring Machines.

Machine. *36 in. Centre Lathe. 90 ft. long.*

Drive. By a short belt from rocking countershaft. Motor drives countershaft by steel spur gearing.

Motor. 10 B.H.P. 600 r.p.m. Shunt.

Work. 9·2 in. gun tube. Weight about 5 tons, diameter 20 in. Hard steel, cutting speed 5 ft. per minute.

4 cuts $\frac{3}{16}$ in. × $\frac{3}{16}$ in. traverse = 6·8 B.H.P.

4 cuts $\frac{3}{16}$ in. × $\frac{1}{4}$ in. traverse = 7·5 B.H.P.

Another test on same lathe:—

Work. Mild steel shaft, 11 in. diameter, 16 ft. long.

Cuts $\frac{3}{8}$ in. × $\frac{3}{8}$ in. traverse. Cutting speed 10 ft. per minute.

With no cut Lathe takes 3·1 B.H.P.
With 1 cut „ „ 4·6 „
With 2 cuts „ „ 5·5 „
With 3 cuts „ „ 7·0 „
With 4 cuts „ „ 9·4 „
Rising after half an hour to 10·5 B.H.P.

A similar 36 in. Lathe driven by 10 B.H.P. variable-speed motor, 250–500 r.p.m. through steel spur gearing :—

Work. 23-ton gun tube, forging hard steel.
Running light = ·6 B.H.P.
4 cuts $\frac{3}{8}$ in. × $\frac{1}{4}$ in. traverse. 10·7 B.H.P.
Cutting speed 5 ft. per minute.

Machine. *40 in. Centre Lathe.*
Drive. Belt from motor to countershaft.
Motor. 10 B.H.P. shunt. 600 r.p.m.
Work. Mild steel shaft 36 ft. long, 18 in. diameter, 24 tons.
4 parting cuts each $1\frac{3}{4}$ in. wide × ·05 traverse. 9 B.H.P. taken.
Running without cuts, 3·5 B.H.P.

TESTS OF POWER TAKEN BY LATHES USING VICKERS' HIGH-SPEED TOOL STEEL.

Lathe.	Material.	Cutting Speed.	No. of Tools.	Lbs. of Metal per hour.	Cut.	Traverse.	B.H.P.	Lbs of Metal per B.H.P. hour
36″ Centres	Gun Steel	12′ per min.	1	187	·38″	·166″	9	21
,,	,,	21′ ,,	1	280	·38″	·166″	15·4	18·2
,,	,,	32′ ,,	1	360	·26″	·166″	15·4	23·4
,,	,,	12′ ,,	4	460	28″	·166″	19·8	23·2
,,	Gun (very hard)	8′ ,,	4	110	·50″	·143″	15·0	7·33
,,	Gun steel ingot	51′ ,,	1	502	·99″	·05″	25·5	19·7
,,	Gun steel ingot	48′ ,,	1	570	·58″	·10″	33·0	17·3
,,	Marine shaft (32 tons tensile)	50′ ,,	1	480	·50″	·10″	22·0	21·8
40″ Centres	Marine shaft	13·5′ ,,	8	900	·3″	·25″	39	23
30″ ,,	Gun steel	18′ ,,	2	795	·45″	·188″	30	26·5

Note.—Allowing a tool to cut at such a rate that it requires grinding after two hours' work, the weight removed per hour is about 220 lbs. per tool, and the B.H.P. is about 11 per tool. A lathe with four tool posts can therefore absorb over 40 H.P., but as the four tools are not always cutting equally heavily in roughing, most of the lathes used for roughing in the Sheffield works have motors of 30 B.H.P., with overload capacity up to 40 B.H.P.

Twenty lathes of from 30-inch to 40-inch centres are having 30 H.P. motors fitted in place of the former 10 H.P. motors.

Boring Machines.

Machine. *24 in. Centre Gun Boring Lathe.*
Drive. Motor to countershaft spur gear, belt to lathe.
Motor. 5 B.H.P. shunt, 600 r.p.m.
Work. 6 in. gun tube, boring 8 in. hole out of solid, 3 inches per hour. (Ordinary tool steel.)
5·4 B.H.P. 5·7 lbs. steel per B.H.P. hour.

Machine. *Ingot and Tube Boring Machine.*
Drive. Through steel spur gearing.
Motor. 10 B.H.P. shunt, 600 r.p.m.
Work. Boring 9 in. hole from the solid in 27-ton gun forging (which is rotated).
Traverse $2\frac{1}{4}$ in. per hour. (Ordinary tool steel.)
B.H.P. = 5·5. 8·4 lbs. steel per B.H.P. hour.

Another Test:—
Boring 12 in. hole from solid in 15-ton ingot.
Traverse $2\frac{1}{4}$ in. per hour.
B.H.P. = 7·2. 11·25 lbs. steel per B.H.P. hour.

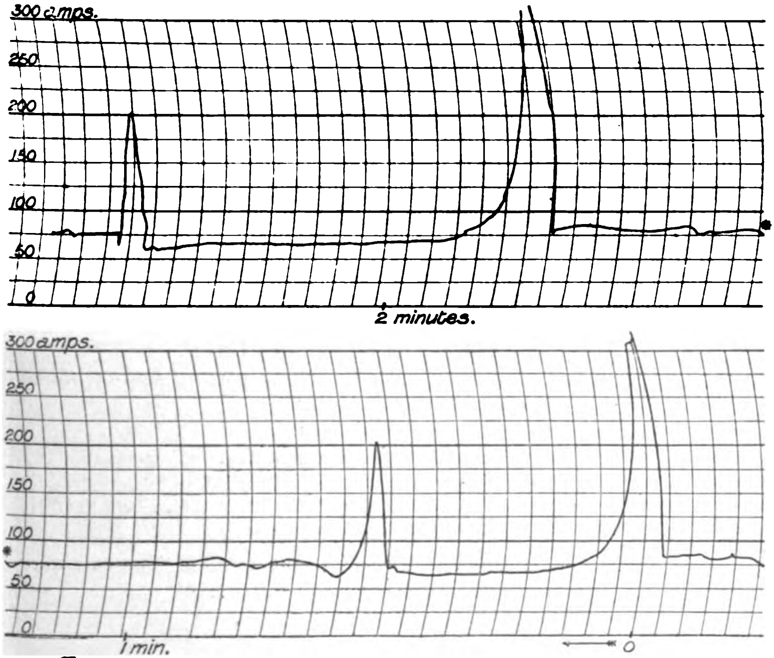

FIG. 1.

Machine. *Double-Barrel Boring Machine for 6 in. Guns.*
Drive. Spur gear and worm gear.
Motor. 10 H.P. Vickers variable speed, shunt, 350–500 r.p.m.
Work. Boring a gun tube from both ends.
Diameter of hole $7\frac{7}{16}$ in. one end, $6\frac{1}{4}$ in. the other end.
Traverse $2\frac{1}{2}$ in. per hour each end. (Ordinary tool steel.)
B.H.P. =8·04. 7·54 lbs. steel per B.H.P. hour.

Machine. *6 in. Gun Boring Machine.*
Drive. Spur and worm gearing.
Motor. 25 B.H.P., variable speed 300 to 900 r.p.m.

Work. Boring $5\frac{1}{16}$ in. diameter hole out of solid gun steel at the rate of 42 in. per hour (21 in. each end) with Vickers' high-speed steel. Power taken = 25·5 B.H.P.

Machine. *12 ft.* × *12 ft.* × *25 ft. 6 in. Planer.* (See Fig. 1.)
Gear. Spur gear and belt reversing.
Motor. 40 B.H.P., shunt, 720 r.p.m.
Work. Parting a 12 in. nickel steel armour plate, 23 tons.
2 tools, each $1\frac{1}{2}$ in. wide, cutting speed 12·5 ft. per minute.
Quick return stroke 30 feet per minute.
Cut and quick return take 17 B.H.P. Reversing takes up to 70 B.H.P.

Class II.—Planing Machines.

Machine. *Heavy Armour-plate Planer,* 10 *ft.* 6 *in.* × 10 *ft.* 6 *in.* × 25 *ft.* stroke.
Gear. Belt drive, open and crossed belts (8 in. wide, double).
Motor. 15 B.H.P., 400 r.p.m., shunt-wound.
Work. (1) Running without cuts, 4-ton plate on table.
Cutting stroke, 4 B.H.P.
Reverse slow to fast stroke, 20 B.H.P.
Quick return stroke, 9 B.H.P.
Reverse fast to slow stroke, 12·5 B.H.P.
Extra for each cut $1\frac{1}{4}$ in. wide parting tool on nickel steel plate = 2 B.H.P.
(2) 12 in. nickel steel plate, 30 tons.
Cutting stroke (no cut on), 7 B.H.P.
Reverse to quick stroke, 24 B.H.P.
Quick return, 15 B.H.P.
Reverse to slow stroke, 15 B.H.P.
The cutting speed was 5 ft. per minute. The cuts were on the hard Harveyised surface.
Extra for each $1\frac{1}{4}$ tool = 2 B.H.P.

Machine. *Side-planing Machine for Armour Plates.*
Gear. Open and crossed double 4 in. belts.
Motor. 5 B.H.P., shunt, 600 r.p.m.
Work. 6 in. nickel armour-plate, cutting in both directions.
Running machine without cut, 1·4 B.H.P.
Cuts $\frac{3}{4}$ in. wide parting tool.
(1) Cutting the hard face, 5 ft. per minute, 4 B.H.P.
(2) Cutting below the hard face, 9 ft. per min., 5·5 B.H.P.

Machine. *4 ft. 6 in.* × *4 ft. 6 in.* × *12 ft. stroke Planing Machine.*
Drive. By belt from motor.
Motor. 10 B.H.P., shunt, 600 r.p.m.
Work. Running belt on loose pulley, 3 B.H.P.

Cutting stroke (no cut on) 19·5 ft. per minute, 3 B.H.P.
Reverse, maximum, 25 B.H.P.*
With 30 cwt. steel forging, two tools cutting 19·5 ft. per min., 5 B.H.P.
Reverse to quick return, 25 B.H.P.*
Quick return, 69 ft. per minute, 7 B.H.P.

Machine. *Planer, 5 ft. 6 in. × 5 ft. 6 in. × 12 ft. stroke.*
Drive. Motor on planer drives countershaft direct at 300 to 400 r.p.m. Open and crossed belts to pulleys.
Motor. 10 B.H.P., shunt, speed variable from 300 to 400 r.p.m.
Work. Planing cast-iron motor frames.
Cut ¼ in. × $\frac{1}{16}$ in., 16 ft. per minute (2 tools).
Quick return, 43 ft. per minute, 5 B.H.P.
Reversing takes 15 B.H.P.
Cutting takes 4·5 B.H.P

Class III.—Slotting Machines.

Machine. 30 *in. Stroke Slotter.*
Drive. Belt.
Motor. 5 B.H.P., shunt, 600 r.p.m.
Work. Slotting gun breech ring, about 24 in. stroke.
(1) Cut ¼ in. × $\frac{3}{64}$ in. traverse, 2 B.H.P.
(2) Roughing cut ¾ in. × $\frac{3}{64}$ in. traverse, 4·5 B.H.P.
Quick return stroke, 1 B.H.P.
(3) The heaviest observed current on any work which the machine will do was equal to 6 B.H.P.

Machine. 36 *in. Stroke Slotter.*
Drive. Belt.
Motor. 10 B.H.P., shunt, 600 r.p.m.
Work. Cutting mild steel, 1¼ in. × $\frac{1}{16}$ in. traverse, 28 in. stroke.
Cutting, 7 B.H.P.
Reverse to quick return, 9 B.H.P.
Quick return, 5 B.H.P.
Reverse to cut, 7 B.H.P.
9 lbs. of steel per B.H.P. hour.

Class IV.—Shipyard Plate Machines.

Machine. *Large Plate Rolls,* 30 *in. wide.*
Drive. Main drive by spur gear into two bottom rolls.
Motor. 45 B.H.P., series reversing, 450 r.p.m., enclosed.
Work. Reversing rolls, about 50 B.H.P. (momentary).
Running rolls light, 15 B.H.P.

* After fitting a C.I. disc 33 in. × 2¼ in. on the motor as a flywheel, the *reversing H.P. was reduced to* 16. As the motor had a high sparking limit, it was kept on the work; the heavy load was not of sufficient duration to affect the temperature.

Bending 16 ft. × 1¾ in. cold plate—
Reversing rolls up to 80 B.H.P. (momentary).
Running, 25 to 30 B.H.P.
A magnetic brake was fitted to stop the motor quickly. It lifted at 45 amperes.

Lifting Gear for above Rolls. Top Roll, 30 *in. diameter.*

Gear. Bevel and worm gear, reduction 100 to 1.
Motor. Two 10 B.H.P. series, 600 r.p.m., one each end of roll.
Work. Raising one end, 10 B.H.P.
Raising both ends, 18 B.H.P.
Lowering one end, 8 B.H.P.
Lowering both ends, 15 B.H.P.
Pressing the roll on to a 9 ft. × 1 in. steel plate, 22 B.H.P.
When motors were brought up all standing, the maximum current rose to 160 amperes. No damage done.
Magnetic brakes fitted to each motor to check the rolls with accuracy when lifting and lowering.

Machine. 6 *ft.* 3 *in., Vertical Rolls.*
Drive. Spur gearing.
Motor. 22 B.H.P. tramway motor, 575 r.p.m.
Work. Bending 3 in. nickel steel gun shield to about 24 in. radius, at dull red heat.
Average load, 25 B.H.P.
Maximum observed, 35 B.H.P.
(As the work is intermittent, the above motor is found to be quite strong enough.)
Auxiliary Motor. 5 B.H.P. series, 600 r.p.m., for feeding the rolls in bending. Fully loaded.

Machine. 10 *in. Boiler Shop Rolls* (converted from engine drive).
Drive. Belt to countershaft carrying old engine pulley and open and crossed belts to machine. Speed of rolls 10 r.p.m.
Motor. 10 B.H.P., shunt, 600 r.p.m.
Work. Running open and crossed belts on loose pulleys, 3·5 B.H.P.
Rolling $\frac{9}{16}$ in. cold plate into 19 in. diameter tube 8 ft. 2 in. long, 11 B.H.P.
Reversing. No noticeable increase.

Machine. Shipyard Rolls—20 *ft.* 6 *in. Rolls.*
Drive. Open and crossed belts to shaft carrying old engine pinion.
Motor. 30 B.H.P., series, 600 r.p.m.
Work. Rolling $\frac{5}{8}$ in. plate, 30 in. wide, 9 B.H.P.
Rolling $\frac{1}{2}$ in. plate, 15 in. wide, 12 B.H.P.
Reversing, 32 B.H.P.

Machine. *Plate Straightener ("Mangle").*
Drive. By open and crossed belts.
Motor. 10 B.H.P., shunt, 600 r.p.m.
Work. Running rolls light, 3 B.H.P.
Rolling ¼ in. plate, cold, 42 in. wide, 4 B.H.P.
Rolling 7/16 in. plate, cold, 48 in. wide, 8 B.H.P.
Reversing, about 10 B.H.P.

Machine. *Small Shearing Machine (used for shearing Rivets).*
Drive. By fibre pinion and cut steel wheel.
Motor. 5 B.H.P., shunt, 600 r.p.m.
Work. Running light, 1·5 B.H.P.
Shearing one ¾ in. rivet at a time, 3 B.H.P.
Shearing three ¾ in. rivets at a time, 4½ B.H.P.

Machine. *Shipyard Punch and Shears.*
Drive. Belt to flywheel from motor in pit. Converted from steam engine drive.
Motor. 5 B.H.P., series, 600 r.p.m.
Work. Punching 1¼ in. holes in ¾ in. ship's plate, 6 B.H.P.
Shearing ¾ in. plate, 9 B.H.P.

Machine. *Heavy Punch and Shears (Three-headed Machine).*
Drive. Belt to flywheel from motor on entablature carried by derrick standards. Converted from engine drive.
Motor. 20 B.H.P., series, 600 r.p.m.
Work. 26½ strokes per minute.
Running light, engine still connected, 9 B.H.P.
Running light, engine disconnected, 3·5 B.H.P.
Shearing 1 in. plate, 17 B.H.P., rising to 24 B.H.P. on a long plate.
Punching 1 in. holes in ¾ in. plate, 7 B.H.P.
As not more than two heads are in use at once, the motor is found to be quite large enough.

Machine. *Horizontal Beam Punch and Shears.*
Drive. Belt to flywheel from motor on entablature.
Motor. 10 B.H.P., shunt, 600 r.p.m.
Work. Running light, 30 strokes per minute, 2·5 B.H.P.
Starting current, 13 B.H.P.
Shearing angle bar, 5 in. × 3 in. × ½ in., 5 B.H.P.
Shearing bulb bar, 9 in. × 3½ in. × 1 in., 9 B.H.P.
Shearing angle, 4 in. × 4 in. × ⅝ in., 9 B.H.P.
Shearing angle, 6 in. × 6 in. × ¾ in., 13 B.H.P.
Shearing bar, 6 in. × ½ in., 5 B.H.P.
Shearing angle, 3 in. × 2¾ in. × ¾ in., 3 B.H.P.

Machine. *Squeezer for Straightening Bars and Rails.*
Drive. Belt from motor on old engine standard.
Motor. 5 B.H.P., series, 600 r.p.m.
Work. Running light, 2 B.H.P.

Straightening a rail, $2\frac{1}{2}$ B.H.P.
Starting, about 10 B.H.P.

The flywheel is very heavy, weighing over 1 ton.

Machine. *Three Plate Countersinks.*
Drive. Belts from a 40 ft. length of 3 in. shaft. Motor drives shaft by belt.
Motor. 10 B.H.P., shunt, 600 r.p.m.
Work. Running three belts on loose pulleys, 2 B H.P.
Running three machines light, $3\frac{1}{2}$ B.H.P.
Three $1\frac{3}{4}$ in. holes countersunk at once in $\frac{5}{8}$ in. plates. Speed of countersinks 130 r.p.m., 11 B.H.P.

Machine. *Two Countersinks and one Edge Planer.*
Drive. Belts from 70 ft. of 3 in. shaft, 160 r.p.m.
Motor. 10 B.H.P., shunt, 600 r.p.m.
Work. All machines on loose pulleys, 3 B.H.P.
Two countersinks working, 8 B.H.P.
Planer alone, $\frac{1}{2}$ in. plate, $\frac{1}{16}$ in. cut, 16 ft. per minute, 10 B.H.P.
Average load, usual conditions, about 14 B.H.P.

Machine. *Scarphing Machine (two Shaper Heads).*
Drive. Belt drive.
Motor. 5 B.H.P., shunt, 600 r.p.m.
Work. $\frac{3}{4}$ in. ship's plate, both heads working.
Cut, taper from $\frac{3}{4}$ in. to $\frac{1}{8}$ in. deep $\times$ $\frac{1}{16}$ in. traverse = 6 B.H.P.

Machine. *Large Edge Planer (25 ft. stroke).*
Drive. Belts, open and crossed.
Motor. 20 B.H.P., shunt, 600 r.p.m.
Work. Planing 1 in. plate, $\frac{1}{10}$ in. cut, 14 ft. per minute = 18 B.H.P. Reversing did not exceed this.

Machine. *Small Edge Planer (12 ft. stroke).*
Drive. Belts, open and crossed.
Motor. 10 B.H.P., shunt, 600 r.p.m.
Work. Planing a ship's plate on the surface.
Cut $2\frac{1}{2}$ in. wide $\times$ $\frac{1}{16}$ in. deep, 14 ft. per min. = 15 B.H.P

This is unusually heavy work for this machine; it seldom takes more than 10 B.H.P.

Class V.—Drilling Machines.

Machine. *Portable Drill up to 2 in. Diameter.*
Drive. Spur gear reduction and Stowe flexible shaft.
Motor. 2 B.H.P. Variable speed, 750 to 1,000 r.p.m.
Work. 2 in. hole in mild steel.
Rate of feed, 0·15″ per minute.
Speed of drill, 30 r.p.m. = 1·5 B.H.P.

CLASS VI.—PUMPS.

Machine. *Centrifugal Pump, 18 in. Outlet.*
Drive. Renold chain.
Motor. 70 B.H.P., 600 r.p.m., shunt.
Work. Lift 29 ft. (maximum) 5,500 gallons per minute. Speed, 275 r.p.m. = 67 B.H.P. (maximum lift).

Machine. *Centrifugal Pump, 8 in. Outlet.*
Drive. Direct, by 20 B.H.P. Motor, 800 r.p.m.
Work. 5 tons per minute, 32 ft. head = 23 B.H.P.

Machine. *Centrifugal Pump, 5 in. Outlet (for Condenser Water).*
Drive. Direct, by 4 B.H.P. series motor, 750 r.p.m.
Work. 2 tons per minute against 12 ft. maximum head = 3·25 B.H.P.

Machine. *Vertical Shaft Turbine Pump, for Raising Condensing Water from the River.*
Drive. By cast-iron bevel gear.
Motor. 5 B.H.P. series, 600 r.p.m.
Turbine. Speed, 350 r.p.m.
Work. Raising 6 tons per minute against 10 ft. head (maximum) B.H.P. taken = 5·15 when the head was 5 ft.

CLASS VII.—CRANES.

As there are 157 cranes of sizes from 1½ to 100 tons, it is quite mpossible to describe many of them. A few of the most important. only are described.

The Table below gives the average ratios of H.P. to lifting capacity

Class of Crane.	Motor B.H.P. per Ton Lifting Capacity.		
	Lift.	Long Traverse.	Cross Traverse.
Melting House	1·0	·6	·25
Foundry	·7	·5	·20
Forge	·4	·4	·17
Gun Shop (Heavy Guns), 17 Cranes	·75	·25	·13
Armour Plate Planing Shop		Single Motor—	·5 B.H.P per ton.
Armour Erecting Shop ...	1·1	·375	·2
Light Machine Shops ...	·8	1·2	·4
2 Tons Electric Lifts ...	9·0	Single Motor	

in different shops. The figures are not by any means adhered to in all cases, many cranes of intermediate lifting capacity having motors a size larger or smaller than the average ratio dictates, for the sake of interchangeability. The ratios stated simply show average values which give satisfactory service under the various conditions.

Number of Motors per Crane.—In most cases there are three motors, one to each motion, although some of the earlier rope-driven cranes were converted to electric cranes by attaching one motor to drive the three existing motions. Experience of both types has proved that the cost of upkeep is less with three motors than with one, and the efficiency

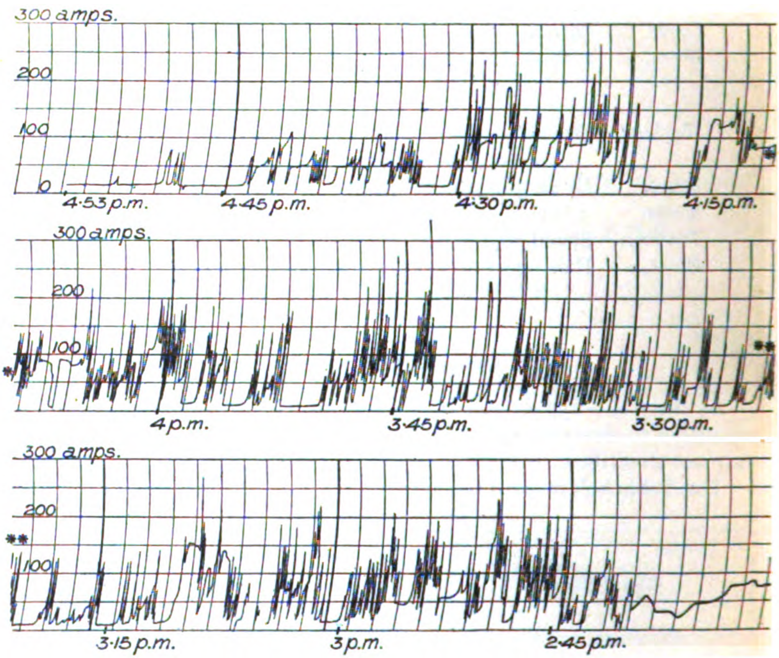

FIG. 2.

is greater. On some of the heaviest cranes five motors are used, there being two crabs, one for light work, to avoid having to lift small weights at the comparatively slow speed limiting the motor of the heavy crab.

In connection with the average current taken by a number of cranes, the diagram (Fig. 2) is of interest. It represents the curve drawn by a recording ammeter in a circuit serving 7 cranes, with 21 motors of a total B.H.P. of 397. This is the largest number of cranes on any single circuit, and the curve only shows to a small extent the tendency of a number of cranes to provide a uniform load. As a matter of fact, although some of the single cranes take 400 or 500 amperes to start them, there is hardly any sudden fluctuation observable

on the main ammeters in the power-house. Fig. 3 shows the record of a single 20-ton 3-motor crane. The average speeds of the different motions are as follows—

	Feet per Minute.		
	Lifting.	Long. Travel.	Cross Travel.
5 Tons Crane	20	300	70
10 " "	15	250	70
20 " "	12	200	60
60 " "	8	150	50

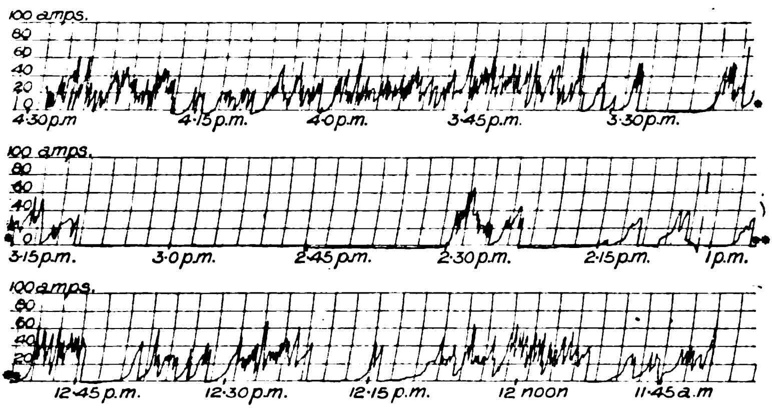

Fig. 3.

The largest crane is a 100-ton crane by the Wellman-Seaver Company of America, in the steel melting house. The span is 46 ft. 6 in., and there are five motors of 260 total B.H.P. in the following units :—

	Motor B.H.P.	Feet per Minute.
Main Crab, Lifting	100	8
Auxiliary Crab, Lifting	50	25
Main Crab, Traverse	25	50
Auxiliary Crab, Cross Traverse ...	5	100
Longitudinal Travel	50	150

Weight of crane and motors = 140 tons.

All motors are tramway type, and all controllers are of the commutator type with magnetic blow-out and iron strip resistances.

Another crane of particular interest is a 60-ton crane in the armour-plate shop, used for dipping the plates in the oil bath. Here it is necessary to lower the hot plate quickly, and accidents have occurred through too quick lowering with the ordinary type of crane bursting the bands of the armature. Any stopping of the plate when half immersed means firing the oil in a tank about 30 ft. deep.

The old 3-motor crane was transferred to another shop and replaced by a 4-motor crane with the following motors:—

Lifting	45 B.H.P.
Travelling	15 „
Cross Traverse	8 „
Pump Motor	4 „

One end of the lifting-rope is wound on a barrel driven by the 45 H.P. motor, the rope then passes over a sheave on the trolley down to the lifting-hook, then up over another sheave on the trolley and along to

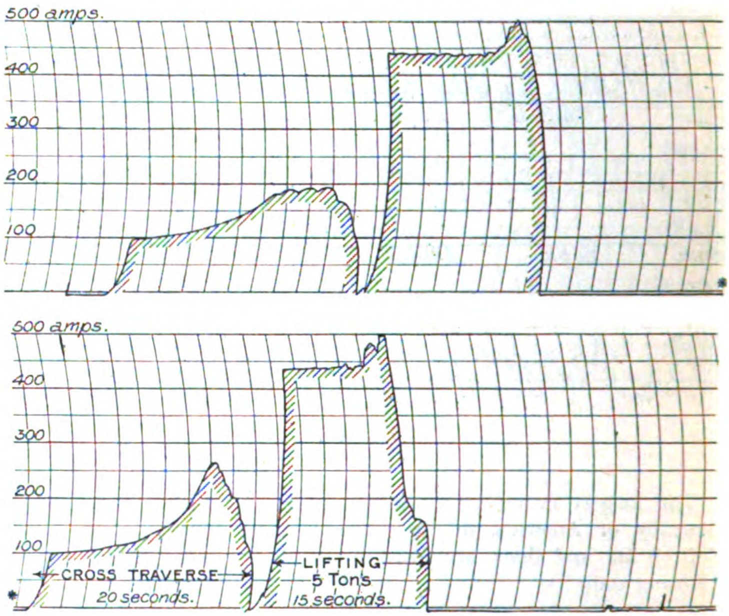

FIG. 4.—Brown Hoisting Co.'s Cantilever Crane.

the end of the crane-girder where it passes several times over sheaves attached to a hydraulic cylinder and ram. Before lifting, the cylinder is pumped full of water, and the ram is forced out to its full extent; lifting is done by the 45 H.P. motor, and lowering is performed as quickly as desired by allowing the water to escape from the cylinder.

Another crane of exceptional interest is that used for the transport of iron ore from the stockyard across the River Don to the railway within the works. The span across the river from track to track is 187 feet, and the overall travel of the trolley is 360 feet, extensions at either end being carried on the cantilever principle.

The three motions for lifting, travelling, and cross-traversing are driven by a series-motor of 85 B.H.P., through clutches; the controllers

are of the tramway type, and the whole is operated by one man in a cab attached to one of the travelling carriages. The height of the trolley rails above water level is 47 feet.

The following readings were taken immediately after erection, when the motions were naturally a little stiff :—

(1)	Travelling ...	...	80 feet per minute.
	„ starting	...	75 B.H.P.
	„ running	...	44 „
	(with 5 tons on hook.)		
(2)	Trolley travel	...	1,000 feet per minute.
	Starting ...	...	64 B.H.P.
	Running ...	...	32 „
(3)	Hoisting ...	...	400 feet per minute.
	Starting ...	...	100 B.H.P.
	Running ...	...	100 „

The curve (Fig. 4) shows the current taken (at 200 volts) when lifting a weight of 5 tons, transporting it across the river and lowering it into a railway truck. There are four similar cranes at the Barrow Shipyard, two over the building berths, and two in the plate and stockyards. The motors are of the same power, and the arrangements generally are similar except that the overhangs are much longer.

The ship cranes are 320 feet overall, and run on trucks about 730 feet long and 80 feet above the ground, carried on steel gantries. They will lift 15 tons, and the speeds of the respective motions are stated below.

Lifting 15 tons	125 feet per minute.
„ 7½ „	300 „ „
„ ½ ton	700 „ „
Trolley travel	400 to 800 „ „
Crane „	400 to 700 „ „

These cranes are of the greatest service in accelerating the building of ships and placing the armour.

CLASS VIII.—METAL SAWS.

Machine. *Armour-Plate Sawing Machine.*
Drive. Cut steel spur gear.
Motor. 5 B.H.P., shunt, 600 r.p.m.
Work. Sawing 2½ in. thick armour-plate.
One saw 38 in. diameter × ¾ in. thick.
Speed of saw teeth 13·5 ft. per minute.
Rate of cutting, 9 in. per hour.
Power taken = 3 B.H.P.

Machine. *Double Armour-Plate Saw.*
Drive. Belt from motor to machine.

Motor. 10 B.H.P., shunt, 600 r.p.m.
Work. Sawing two plates, $2\frac{1}{2}$ in. and 2 in. thick respectively.
Speed of saw teeth, 15·7 ft. per minute.
Rate of cutting plates, 6 in. and 10 in. per hour respectively.
Power taken = 7 B.H.P.

Machine. *Crank Web Sawing Machine.*
Drive. Four reductions from motor to saw by steel spur gear.
Motor. $2\frac{1}{2}$ B.H.P., shunt, 900 r.p.m.
Work. Sawing out web of locomotive crank 13 in. deep.
Two saws in use, each $\frac{7}{8}$ in. wide, 47 in. diameter.
Speed of saw teeth = 10 ft. per minute.
Rate of cutting (each saw), 3·6 in. per hour.
Power taken = 2·25 B.H.P.
15 lbs. of steel removed per B.H.P. hour.

Machine. *Band Saw.*
Drive. By Renold chain.
Motor. 3 B.H.P., variable speed, 600 to 900 r.p.m.
Work. Sawing steel ingot, 14 in. deep, saw $\frac{1}{16}$ in. thick.
Speed of saw 132 ft. per minute, feed $\frac{1}{4}$ in. per minute = ·90 B.H.P.

CLASS IX.—WOOD-WORKING MACHINES.

Machine. 35 *in. Circular Saw.*
Drive. Belt from motor to saw, 3 to 1 ratio.
Motor. 15 B.H.P., shunt, 600 r.p.m.
Work. Cutting 10 in. teak about 8 ft. per minute.
Power taken = 14 B.H.P.

Note.—Belt slipping prevented a higher speed of cutting; with a better drive a 20 H.P. motor would be required.

Machine. 24 *in. Circular Saw (portable).*
Drive. Direct from motor spindle.
Motor. 4 B.H.P., shunt, 1,500 r.p.m.
Work. Sawing 6 in. beech 4 ft. per minute = 4 B.H.P.
Sawing 2 in. white pine 10 ft. per minute = 2·75 B.H.P.
Saw running light = ·55 B.H.P.

Machine. *Band Saw (Driving-wheels* 36 in.). *Saw* $\frac{1}{2}$ *in. wide.*
Drive. By Renold chain. (Saw speed 3,670 ft. per minute.)
Motor. 2 B.H.P., shunt, 1,000 r.p.m.
Work. Sawing $3\frac{1}{2}$ in. Kauri pine = 1·43 B.H.P.
Sawing $9\frac{3}{4}$ in. Kauri pine = 2·8 B.H.P.
Sawing $7\frac{1}{2}$ in. yellow pine = 1·63 B.H.P.

Machine. *24 in. Circular Saw.*
Drive. Belt, speed of saw 1,000 r.p.m.
Motor. 10 B.H.P., shunt, 600 r.p.m.
Work. Cutting 5 in. ash, about 10 ft. per minute.
Power taken = 6 B.H.P.

Machine. *Sawmill Circular Saw (to take 60 in. diameter Saw).*
Drive. Belt, speed of saw 750 r.p.m.
Motor. 30 B.H.P., shunt, 600 r.p.m.
Work. Sawing damp pitch pine 12 ft. per minute, thickness from 10 to 17 in. (average 14 in.).

Power taken $\begin{cases} \text{Maximum, 36 B.H.P.} \\ \text{Minimum, 21 B.H.P.} \\ \text{Mean, 26 B.H.P.} \end{cases}$

Machine. *Grating Saw.*
Drive. Belt.
Motor. 10 B.H.B., shunt, 600 r.p.m.
Work. Cutting 4 grooves 1⅞ in. wide × ¾ in. deep in teak.
Speed of cutting, 2 ft. per minute.
Running light, 2½ B.H.P.
Grooving, 10 B.H.P.

The drive is a bad one, with jockey pulleys for the belts.

Machine. *Wood Planing Machines (36 in. wide).*
Drive. Belt.
Motor. 10 B.H.P., shunt, 600 r.p.m.
Work. Planer running light, 2½ B.H.P.
$\frac{3}{16}$ in. cut off 27 in. wide pine 14 ft. per min. = 8 B.H.P.
$\frac{5}{16}$ in. cut off 12½ in. wide teak 14 ft. per min. = 6 B.H.P.
¼ in. cut off 22½ in. wide teak 14 in. per min. = 7 B.H.P.

Machine. *Wood Moulding Machine.*
Drive. Belt.
Motor. 10 B.H.P., shunt, 600 r.p.m.
Work. Cutting teak about 5 in. square on three sides and ploughing fourth side, moulding passing through 13 ft. per minute = 10·5 B.H.P.

Machine. *Wood Planing Machine (24 in. wide).*
Drive. Belt.
Motor. 5 B.H.P., shunt, 600 r.p.m.
Works. Planer speed, 2,200 r.p.m.
Planing 16¼ in. pine ⅛ in. cut, 14·5 ft. per min. = 3·25 B.H.P.
Planing 16¼ in. pine $\frac{1}{32}$ in. cut, 14·5 ft. per min. = 2·5 B.H.P.
Planing 14 in. pine ⅛ in. cut, 14·5 ft. per min. = 3 B.H.P.

Class X.—Special Machines.

Wellman Charging Machine for Steel Furnaces.

This machine consists of a carriage running alongside the furnaces on rails 12 feet gauge, having the following motions :—

(1) Longitudinal motion on the rails, 25 H.P. tramway motor.
(2) Cross traverse of the crab or charging platform, driven by a 25 H.P. tramway motor. This crab carries the operator and all the controllers, with the two other motors.
(3) Raising the porter bar which lifts the charge of metal in special tubs, 25 H.P. tramway motor.
(4) Turning gear for turning the bar and tubs over, to empty the charge into furnace, 5 H.P. enclosed motor. All motors drive through steel cut gears.

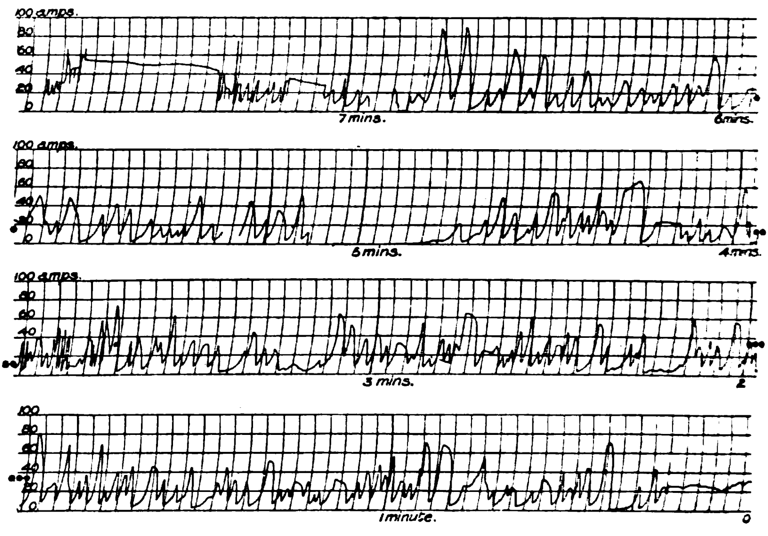

Fig. 5.

The method of working is as follows :—The operator runs the charger along until opposite the furnace door. He then runs the bar forward and lowers it into the slot in the end of tub, which is placed ready on a trolley with others, making the complete charge. The bar is lifted, and when high enough it is run forward into the furnace and turned over, discharging the metal into the furnace. The bar is then withdrawn, and the next tub is emptied in the same way. Two chargers are in use, one on each stage of the melting house.

Power, charging tubs each containing 3 tons, average = 7 B.H.P.
Maximum observed ... ... 40 B.H.P.

It is interesting to compare the cost of charging a 40-ton Siemens furnace by the Wellman charger with the cost of charging by manual labour. Under the former conditions of hand-charging it was necessary to have four highly paid men per furnace, whose earning depended on the tonnage of output; also there were additional helpers kept to give occasional assistance in handling heavy pieces of scrap. The time taken to charge 40 tons was four hours. Now two men are employed in place of four, and the same operation is performed in half an hour, or one-eighth of the former time. (For recording ammeter diagrams, see Fig. 5.)

The output is naturally increased very largely. One man, taken from the ranks of the labourers, made a skilful operator on the Wellman charger with a few days' training, and he attends to six furnaces. The furnace men are relieved of much of the laborious part of their duties, and are at liberty to give better attention to the more skilful part of their work. Also, in the hot part of the year the output is the same as in cool weather, while formerly, with hand-charging, a reduced output was accepted as a natural consequence of hot weather.

Summing up the advantages, we have a reduction in the wage costs of melting of 50 per cent., with an increase in the output of 25 per cent., and the life of the furnaces is considerably extended, consequently repairs are lighter.

The 40-ton charge by the Wellman charging machine takes three Board of trade units at 0·75d. = 2¼d. for power.

	Hand Charging.	Electric Charging.
Capacity of furnace	40 tons	40 tons
Time taken	4 hours	½ hour
Men engaged per furnace	4 + occasional help	2 + ⅛th of the operators' time
Wages per ton	2s. 8d.	1s. 3d.
Electric power	—	2¼d.
Charges per furnace per week ...	9	12

Trepanning Machine. (*Two Trepanning Bars.*)

For boring ingots and gun tubes, leaving a solid core. The bar revolves.

Drive. Spur gearing.

Motor. 15 B.H.P. variable-speed shunt motor, 250–500 r.p.m.

Work. Boring two 6 in. "B" tubes in one piece.

The end of each bar carries 8 tools. (Ordinary tool steel).

Diameter of hole = 9⅜ in., feed 3 in. per hour each bar = 12·4 B.H.P.

Pump for washing out boring driven by a 5 B.H.P. motor.

Another Test, with Vickers High-Speed Tool Steel.

Machine. Similar to the above, but with only one bar.
Motor. 25 B.H.P., variable speed, 300 to 900 r.p.m.
Work. Boring a 14″ hole in steel ingot.
Rate of feed, 10½″ per hour.
Power taken = 22 B.H.P.

A similar machine (single bar only) trepanning a 21⅜ in. hole in a steel ingot takes 10·9 B.H.P.
Feed = 2¼ in. per hour. (Ordinary tool steel).

Hauling Crab for Furnaces.

A fixed crab, driven by a 5 B.H.P. motor through spur gear, hauls the car carrying armour plates into and out of the furnace by endless chain engaging in sprocket wheels.
Six-wheeled car, carrying 36 tons of plates hauled at the rate of 30 ft. per minute.
Mean power taken = 5 B.H.P.
Maximum „ = 5·25 B.H.P.

Manganese Crusher.

Belt driven from 10 B.H.P., shunt motor, 600 r.p.m.
Running light = 2·5 B.H.P.
Crushing = 9 B.H.P.

Brick Crusher.

Driven by belt from 10 B.H.P. motor, 600 r.p.m. (shunt).
Work. Crushing old bricks and furnace linings for concrete.
Running light = 1·75 B.H.P.
Crushing = 9·5 B.H.P.

Mortar Mills.

(*a*) With driven rolls and fixed tray.
Belt driven from 10 B.H.P. shunt motor, 600 r.p.m.
With tray full of mortar = 12·5 B.H.P.
(*b*) With fixed rolls and driven tray.
Belt driven as (*a*)
With tray full = 9 B.H.P.

Power Hammer, 5 *cwt. size.*

Vertical hammer with pneumatic cushioning.
Belt driven from 10 B.H.P., shunt motor, 600 r.p.m.
Work. Hammering out wedges for shipyard use, about 6 in. × 8 in., 1 in. thick tapered to nothing.
Hammer striking = 4·75 B.H.P.
Cushioning = 9 to 10 B.H.P.

Note.—A series motor would be better for the work, about 5 B.H.P. It would drop its speed when cushioning, and not take more than about 6 or 7 B.H.P.

Stern Tube Boring Machine.

Starboard tube of H.M.S. *Hogue.*
8 in. diameter bar driven by a worm-wheel and worm, which is driven by a 10 B.H.P. shunt motor, 600 r.p.m., through chain gear and bevel wheels.
Speed of bar, 1·36 r.p.m.
Diameter of hole bored, 26½ in.
Cutting speed of tools, 9·5 ft. per minute.
Running bar light = 2 B.H.P.
Four tools cutting $\frac{3}{16}$ in. = 10·1 B.H.P.

Armour-Plate Grinders.

There are seven of these machines, each consisting of a long bed on which travels a saddle carrying the grindstone and motor. The motor spindle is extended through a heavy bearing, and carries the chuck into which segments of grindstone are wedged. The speed of motor and grindstones is 400 r.p.m. The motors are of two sizes, 20 B.H.P. and 40 B.H.P., with good overload capacity. The work consists of facing up the edges of armour plates, which to a certain depth are too hard to be machined in a planer. The thickness of plate varies from 2 inches to 12 inches, and the power taken varies from 20 to 60 B.H.P. It is very easy to overload the motors, a slight movement of the feed-wheel presses the grindstone hard against the work, and the current sometimes rises to the equivalent of 80 B.H.P. Heavy fuses are found better than overload release starters, as they are not too sensitive, and by becoming red-hot warn the grinder to ease his cut.

CLASS XI.—FANS AND BLOWERS.

Steel Foundry Converter Blowers. (Roots.)

Capacity of converter, 2 tons.
Blower direct driven by 75 B.H.P., shunt motor, 500 r.p.m.

Pressure in Converter.	B.H.P.
1·5 lbs.	40
1·75 „	45·5
2·0 „	48·25
2·25 „	53·5
2·5 „	61·5

Iron Foundry Cupola Blowers. (Roots.)

Charge melted per hour, 8 tons (maximum possible, 9 tons).
Blower driven direct by 75 B.H.P. shunt motor, 500 r.p.m.

Pressure in Cupola.	B.H.P.
Running light	23
14 ozs.	70
15 „	73

Iron Foundry Cupola Blowers. (Roots.)

Charge melted per hour, 3 tons (maximum possible, 4 tons).
Blower belt-driven by 40 B.H.P. shunt motor, 500 r.p.m.

Pressure in Cupola.	B.H.P.
9 ozs.	34
9½ „	35·5
10 „	37

Steel Foundry Cupola Fan. (Sturtevant.)

Charge melted per hour, 2 tons (maximum possible, 4½ tons).
Belt driven by 20 B.H.P. shunt motor, 600 r.p.m.

Starting	16 B.H.P.
Running light	11 „
Blowing	12 „

Fan for Smiths' Fires.

1,400 revolutions per minute, belt driven from motor 5 B.H.P. 600 r.p.m.

Work—9 fires.

Load—average 5 to 5·5 B.H.P.

48 *in. Fan with* 20 *in.* × 20 *in. Outlet.*

Belt driven at 1,000 r.p.m. by a 10 B.H.P. shunt motor, 600 r.p.m.

Work—23 smiths' fires and air blast for chemical laboratory = 8·5 B.H.P.

Roots Blower—No. 2 "1900" *Pattern.*

Driven by belt from 10 B.H.P. shunt motor, 600 r.p.m.

Work—8 fires + heavy lead melting-pot.

Speed of blower = 190 r.p.m.
= 6·4 B.H.P.

Portable Air Compressor (for Working Pneumatic Chippers).

Size of compressor, 4 cylinders 10 in. diameter × 6 in. stroke.
Drive—Spur gear.
Motor—15 B.H.P., shunt, 350 r.p.m.
Air pressure—70 lbs. per sq. inch.
Work—6 chipping tools or 3 drills.
Power = 15·3 B.H.P.

Portable Painting and Lime-washing Machine.

Works two paint sprays.
Motor—2½ B.H.P., shunt, 1,200 r.p.m.
Speed of compressor—102 r.p.m.
Gear—Worm, single reduction.
Air pressure—10 lbs.
Power = 2·6 B.H.P.

LINE SHAFT TESTS.

Speed on all Shafts about 120 revolutions per minute.

No. of Shaft.	Shaft. Length.	Shaft. Dia. (inch.)	No. of Machines.	Class of Work turned out.	Rows of Machines.	Average Size of Machine.	B.H.P. per 100 feet of Shaft.
1	330	$3\frac{1}{4}$	13	Large Engine Work	1	7 Drills, about $4\frac{1}{2}$ in. holes ; 3 Wall Planers, 7 ft. to 18 ft stroke	5·35
2	155	$3\frac{1}{4}$	30	General Engine Work ...	5	11 Lathes, 8 in. to 12 in. centres ; 5 Planers, 6 in. to 12 in. stroke ; 2 Slotters, 4 in. to 5 in. stroke, etc.	16·65*
3	240	$3\frac{1}{4}$	17	" " "	5	6 Drills, 3 in. diameter ; 6 Lathes, 12 in. centres, etc.	7·17
4	155	$3\frac{1}{4}$	45	Small Engine Work	6	6 Shapers, 16 in. to 24 in. stroke ; 7 Milling Machines, 3 in. cutters ; 9 Drills, 3 in. diameter, etc. ; 11 Screwing Machines, $\frac{5}{8}$ in. to 6 in. bolts	13·16
5	265	$3\frac{1}{4}$	38	General Engine Work ...	5	39 Lathes, 6 in. to 12 in. centres	7.28
6	200	$3\frac{1}{4}$	36	" " "	5	7 Slotters, 12 in. to 24 in. stroke ; rest small drills, etc.	7·0
7	290	$3\frac{1}{4}$	68	Brass Engine Work	5	46 Lathes, 8 in. to 30 in. ; 8 Drills, 3 in. diameter ; rest small machines	7·69
8	130	3	30	Gun Mounting Work	3	24 Lathes, 8 in. to 14 in. centres ; 4 Automatic Machines, $\frac{5}{8}$ in. to $2\frac{1}{2}$ in. bore ...	10·0
9	130	3	71	" " "	5	25 Lathes, 8 in. to 12 in. centres ; 33 Milling Machines up to $11\frac{1}{2}$ in. cutters	16·5*
10	20	3	10	" " "	2	All Capstan Lathes, $\frac{5}{8}$ in. to $2\frac{1}{2}$ in. bore	5·0*
11	200	3	45	" " "	3	41 Lathes, 8 in. to 25 in. centres ; rest small machines	10·75
12	200	3	43	" " Fittings ...	5	17 Slotters, 3 in. to 16 in. stroke ; 14 Planers, 3 ft. 6 in. to 12 ft. stroke ; 5 Boring 3 in. spindles	9·9
13	200	3	30	" " "	2	8 Radial Drills, 2 in. diameter ; 6 Wheel Cutters to 20 in. stroke	10·5
14	55	3	4	" " "	2	Planers, 8 ft. to 12 ft. stroke	31·3*
15	140	3	36	" " "	5	30 Lathes, 6 in. to 22 in. centres ; rest small machines	12·7
16	200	3	33	" " "	3	6 Planers, 6 ft. mean stroke ; 6 2 ft. Stroke Shapers ; 6 Lathes, mean 15 in. centres	11.6
17	200	3	23	" " "	3	15 Lathes, 8 in. to 15 in. centres ; 7 Boring, 3 in. spindles	6·65
18	180	3	74	" " "	4	37 Lathes, mean 10 in. centres ; 10 Drills, 2 in. diameter ; rest medium Slotters and Millers	9·56
19	100	3	15	Grinding and Polishing ...	2	7 Emery Wheels, to 14 in. diameter ; 4 5 ft. Grindstones	10·7
20	100	$3\frac{1}{4}$	24	Pattern Shop (Engne)	3	5 Saws, 24 in. ; 4 Planers, 12 in. to 26 in. ; 11 Lathes, 14 in. centres	15·5*
21	220	$3\frac{1}{4}$	8	Ordnance Plate Work... ...	2	4 2 in. Drills ; rest small machines and slotters	4·41*
22	200	$3\frac{1}{4}$	8	" " "	2	Band Saws, Drill, Punch and Shears, Fan, etc.	4·5*
23	130	3	8	" and Boiler Work	1	6 Drills, $\frac{5}{8}$ in. to $2\frac{1}{2}$ in. ; 2 Band Saws	4·6*
24	220	$2\frac{1}{2}$	21	Boiler Work	2	8 Screwing, $\frac{1}{2}$ in. to 5 in. diameter ; 3 Planers, 5 ft. to 15 ft. stroke ; punches, etc.	9·18
25	245	$3\frac{1}{2}$	32	Shells	3	All 12 in. to 16 in. Lathes	10·8*
26	80	$3\frac{1}{2}$	26	"	3	26 12 in. Lathes	19·4*
27	150	$3\frac{1}{2}$	19	"	4	19 10 in. to 16 in. Lathes	9·6
28	150	$3\frac{1}{2}$	22	"	2	22 $4\frac{1}{2}$ in. to 17 in. Lathes	8·5
29	360	3	63	Ships' Fittings	7	19 Lathes, 15 in. centres ; 10 Drills, 2 in. diameter ; 7 Screwing and Tapping, 2 in. diameter ; 9 medium size Planers, Slotters and Millers	5·6

* Special work not to be considered as ordinary cases. Average of the remainder = 9·1 B.H.P. per 100 feet of shafting.
The author has used 10 B.H.P. per 100 feet in most cases with good results.

The following tables stating the brake H.P. of motors and number of watts consumed per 1,000 feet of shop area may be of use in forming an idea of the probable size of plant required to drive works of a similar nature.

The figures dealing with plant installed do not vary with the state of trade, busy or slack, as do the figures relating to the current consumed per B.H.P. installed, which are also stated in tabular form. It should be noted that in all cases the figures of current per B.H.P. of motors relate to times of normal trade, and a margin should be allowed to cover the possible requirements during times of extra pressure.

B.H.P. of Motors Installed per 1,000 Square Feet of Shop Area.

Sheffield.	North Gun Shop (Heavy Guns, 6 in. to 12 in.) ...	12·8
	South „ („ „) ...	13·4
	East „ (Gallery over alternate bays, 4·7 in. Guns)	12·0
	Armour Plate Planing Shop	15·4
Barrow.	Shipyard Platers' Shed	4·3
	Woodworking (Joiners and Blockmakers)	3·9
	Engine Department Machine Shop	4·4
	Gun Mountings and small work...	4·3
Erith.	6 in. Gun Mounting and Carriage Department (Gallery over alternate bays)	7·45
	Gun Turnery	3·4
	Woodworking Shop (two stories)	6·5
Wolseley Motor Car Company Ltd.	(all small power machines) ...	1·72

Average Current and Watts (at 220 Volts) taken per B.H.P. of Motors Installed.

		Current.	Watts.
Sheffield.	North Gun Shop	1·2	264
	South Gun Shop (average of 5 circuits)	1·36	299
	East Gun Shop	1·02	224
	Railway Axle, etc., Turnery	1·27	279
	Cranes in Gun Shops (eight 60-ton cranes on the circuit)	0·5	110
Barrow.	Shipyard Platers' Shed	1·05	231
	„ Woodworking Shop ...	1·63	358
	Engine Department Machine Shop ...	2·06	453
	Gun Mounting and small work bays...	1·76	392
Erith.	Whole Works (Guns and Gun Mountings small)	1·15	253
North Kent.	Field Gun Carriages, etc	1·8	396

	Current.		Watts.
Electric and Ordnance Accessories Company, Ltd. (at 110 volts)	5·0	...	550
The current and watts required at 220 volts to give 1 B.H.P. with an average efficiency of 80 per cent. (allowing for motors working slightly under full load) are ...	4·24	...	932

Total Number of Arc and Incandescent Lamps.

	Arc Lamps.	16 c.p. Incandescent.
Sheffield	558	3,500
Barrow	720	4,000
Erith	400	3,500
North Kent	60	400
Wolseley	80	750
Electric and Ordnance	48	900
	1,866	13,050

Total Number and H.P. of Cranes—Electrically Worked.

	No. of Cranes.		B.H.P. of Motors.		No. of Motors.
Sheffield	89	...	2,683	...	170
Barrow	57	...	1,542	...	145
Erith	11	...	216	...	33
	157		4,441		348

Number of 500-Watt Arc Lamps and Kilowatts per 1,000 Square Feet Shop Area.

		Killowatts.		Number.
Sheffield.	North Gun Shop	·448	...	·90
	South Gun Shop	·401	...	·80
	East Gun Shop	·360	...	·72
	Armour Plate Planing Shop	·320	...	·64
	Marine Crank Turnery	·390	...	·78
	Railway Crank and Small Machine Shop...	·250	...	·50
	Iron Foundry	·234	...	·47
	Steel Melting House	·257	...	·51
	Forge	·320	...	·64
	Repairing Shop	·330	...	·66
	Boiler Shop	·356	...	·71
Barrow.	Shipyard Platers' Shed	·310	...	·62
	Woodworking Shop	·275	...	·55
	Engine Department Machine Shop ...	·375	...	·75
	Boiler Shop	·35	...	·70
	Iron Foundry	·21	...	·42

		Killowatts.	Number.
	Steel Foundry	·25	... ·50
	Gun Mountings and small work	·45	... ·9
Erith.	6 in. Gun Mounting and Carriage Department*	·70	... 1·4
	Gun Turnery*	·68	... 1·37
	Mechanism and Shell Department* ...	·68	... 1·36
	Field Carriage Erecting Shop	·46	... ·92
Wolseley Tool and Motor Car Co., Ltd.		·376	... ·755

Average Figures.

Heavy machine shops (average height of lamps = 35 ft.) = 400 watts per 1,000 sq. ft. of floor area.

Light work (average height of lamps = 16 ft.) = 375 watts per 1,000 sq. ft. of floor area.

Foundries and steel melting = 240 watts per 1,000 sq. ft. of floor area.

Forge, about 350 watts per 1,000 sq. ft.

These figures vary considerably with the amount of reflection which the walls provide and the possibility of keeping the walls clean.

Although a great deal might be written on the subject of starting gear, switchboards, types of arc lamps, fuses *versus* circuit breakers and many other points all of importance to those interested in the use of motors, the author feels that this paper is sufficiently long without reference to most of them. It would be interesting to hear some experiences of engineers with circuit breakers fitted in such power installations as those described in this paper.

The author has a preference for starters without automatic overload release, and has had to do away with the overload release on a number of starters which were continually giving trouble by switching off when overloaded momentarily. The time-constant of a fuse is a very strong point in its favour, as it will carry a motor over a heavy load of short duration which would at once open the automatic. Also, a fuse's sensitiveness is not affected by vibration, as is the case with most of the automatic overload arrangements. If automatic circuit breakers are fitted on the generator panels, they should also be fitted to feeder panels and to all motors, as the presence of even a small fuse may cause a very large generator to come off load before the fuse has time to melt.

Saving due to Electric Driving.

As the available figures under this head have been published frequently, it will be as well to keep entirely to results obtained by the Vickers Company. The difficulty of stating the saving in terms of simple comparison is very great. When a concern takes up electric driving in earnest, it usually finds that many operations become possible

* An attempt was made here to light entirely by arc lamps, but for the fine machining and fitting incandescent lamps are found necessary.

which were not possible before; consequently new machinery is ordered.

The author does not know a single instance where the conditions of working were the same before and after conversion of works to electric driving.

At Barrow, as already stated, an extension of the shipyard, approximately equal to 50 per cent. increase in the power taken, marched hand in hand with the conversion to motor driving. Also, electric lighting had been largely extended. *The actual result was a saving of half the coal bill, with an increase of over 50 per cent. in output.* In no other instance is it possible to express so direct a comparison.

Where boilers have been relieved of a part of their load through motor driving, the steam set at liberty has been used for other purposes, such as working additional hammers, presses, or other hydraulic plant.

It is disappointing to find that the saving, which is so thoroughly evident to those who use electric driving, cannot be more clearly stated. It is only by considering such cases as the charging machine, where much labour is dispensed with, that an idea can be formed of the magnitude of the saving in works where there are many instances of a similar kind.

In the armour-plate planing shop, now driven by three engines developing over 600 B.H.P., motors are being installed. There will be a saving of six engine drivers (one to each engine on day and night shift), against which there will only be a proportion of the wages of one engine driver in the power-house to be charged. In this shop, which has six cranes of 60 tons lifting capacity, recently converted to electric driving by fitting six single motors in place of 5,200 feet of ropes, a saving of £180 per annum has been effected under the head of rope renewals alone. A very large saving is also made by cutting out the constant loss due to keeping the mile of rope running, and the rate of handling the heavy weights has been doubled. Formerly the repairs to the rope pulleys and running gear formed a very heavy item.

The number of stand-by men in works dealing with heavy weights can be greatly reduced by the judicious use of motors. A few years ago it was usual to keep a gang of men to do such odd jobs as opening furnace doors, and on the large furnaces six men were required to raise some of the heavy doors. Now this operation is performed by a 1¼ H.P. motor, and only as many men are employed as can be kept fairly busy.

The author thinks that the future applications of motor driving will be largely in the direction of doing all the rough, heavy work, which is now left to labourers through the shortsighted policy of many employers who will not see that the outlay on motors is soon recovered. A man can do work which a motor cannot, and he should be set free to do that work. As a machine he is not very efficient. The spectacle of six ordinary men pulling on the fall of a rope in as many different directions proves this fact.

The author wishes to express his indebtedness to Messrs. Vickers, Sons & Maxim, Ltd., for their kindness in allowing him a free hand in

publishing the figures in this paper, and also to the following gentlemen for assistance in taking the various tests:—

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ELECTRIC DRIVING IN MACHINE SHOPS.

By A. B. CHATWOOD, B.Sc., Member.

The subject of electric driving has of late years received considerable attention, but there seems to be a great deal of misapprehension in the public mind as to the attitude adopted by electrical engineers in the matter. The author has frequently been told by managers and principals of works that they would wait until electrical engineers had come to some conclusion as to which was the best system and the best method.

Discussions have taken place in this room and elsewhere as to whether direct or alternating current was the more suitable for tool driving, as to whether the final solution of the problem would be one motor per tool or one motor per line shaft, and so on. Whatever value such discussions may have in the abstract, the author is of opinion that in each particular case of machine tool driving electrical engineers would have substantially the same views, and he therefore proposes to leave all discussion of abstract points alone, and to ask the attention of members to three particular cases, out of those which have come closely under his own observation, and to the conclusions to which they lead.

There are, however, a few general questions to which attention may very well be drawn at this point.

Wherever possible, it is desirable to employ direct rather than alternating current, as speed control is of extreme importance with regard to some classes of engineering tools.

The system and voltage to be employed should be such that the installation may either permanently or temporarily be connected to the town mains.

Where, for any reason, a qualified electrician cannot be maintained on the staff, the installation should involve only apparatus which is well understood in the district, so that help or advice can always be readily obtained.

As a general rule it will, the author thinks, be wise to group tools together for driving purposes to a very large extent, but at the same

time to drive certain classes of tools individually. The average number of tools per motor is difficult to arrive at, but in engineering shops doing partly standard and partly odd work of medium weight, the best number will probably work out at from two to four.

The particular cases which it is proposed to submit are those of two

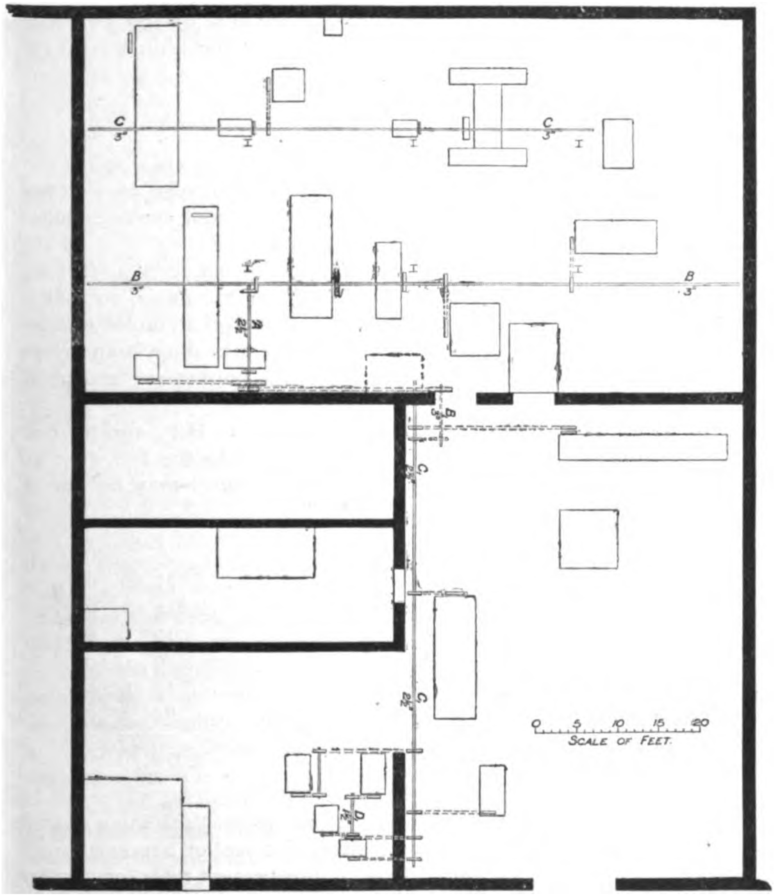


FIG. 1.

old and one new works, all of small size. Plans of all three are shown.

In Bolton, where these shops are situated, direct current is supplied on a three-wire system at 460 and 230 volts, and motors may, under certain circumstances, be hired from the Corporation at 10 per cent.

per annum on the cost of motor, starting switch and fixing, the price of energy being as follows :—

First 500 units per quarter...	... ...	2·25d. per unit.
Second „ „	... ...	1·35d. „
Further consumption	... ...	1·00d. „

The author proposes to take these terms for interest and depreciation, and these prices for current, as a basis for the estimates in the present paper.

Case I.

Until May, 1901, the shop shown in Fig. 1 was driven by a Robey portable made at a very early date, and by a small single-cylinder horizontal with vertical boiler placed in the smithy.

At this time the engines were entirely worn out, and in fact for some years previously the repair bill had been enormous, so that it was decided to adopt electric driving, and a 20 B.H.P. motor was installed in the position shown on plan. The shop has since been driven by this motor, with results which are entirely satisfactory except as regards cost and occasional stoppage.

The actual mean load, including shafting, was 15 H.P., and the cost of steam driving somewhat as follows. Owing to the fact that no proper cost books are kept in this works, these figures may be one or two per cent. wrong either way :—

	£	s.	d.
Wages	72	16	0
Coal...	213	7	6
Water	10	6	0
Ash removal	6	0	0
Oil	15	0	0
Repairs	61	0	0
	£378	9	6

for a year of about 2,800 working hours, or about £434 for a year of 3,194 hours. These figures are exclusive of interest or depreciation.

The cost of the single motor drive, at the present rates for current is £186 7s. 2d., as follows :—

	£	s.	d.
10 per cent. on motor, etc.	18	5	0
Cleaning	1	10	0
Brushes	1	16	0
Current	164	16	2
	£186	7	2

The consumption for six months being as follows :—

Date.	Total Units.	Max. Current.	Hours of Running.
June 19 to July 37	2,668	31 amps.	268·5
August 22	3,140	32 „	249·5
September 20 ...	3,123	36 „	274
October 18 ...	3,119	36 „	295·5
November 20 ...	3,170	35 „	249·5
December 20 ...	3,182	32·5 „	269
	18,402		1,597

Mean consumption, 11·52 units per hour = 15·44 E.H.P.
Max. „ „ „ = 22·2 „

Measurements of the current required to drive the shafting alone, including belts and loose pulleys, gave as mean figures :—

9·72 units per hour ... ... 12·9 E.H.P.

We have therefore in this case—

Useful load ... ... 2·54 E.H.P.
Waste load ... ... 12·9 „

even if we assume, which is certainly not true, that the shafting, etc. absorbs the same amount of power when loaded as when unloaded.

You will notice that the motor drives a cross-shaft A, which in its turn drives at one end a line shaft B, and at the other end an intermediate B′; each of these drives a second shaft C C′, and each of these again drives machine counter-shafts or in some cases another intermediate D′.

This arrangement is not such as would be put up to-day by any self-respecting engineer, but it is typical of a very large class of works which have grown little by little, and in which a machine and a piece of shafting have been tacked on from time to time; sometimes the machine being put in an awkward position for the convenience of the drive, and sometimes the drive being awkward for the sake of the machine.

Case II.

At the present time the shop shown in Fig. 2 is driven by a single-cylinder condensing beam engine of 6 ft. stroke and 25 in. diameter cylinder. Some time ago I had the pleasure of reporting on the electric driving of this shop. The particulars of the loads are as follows :—

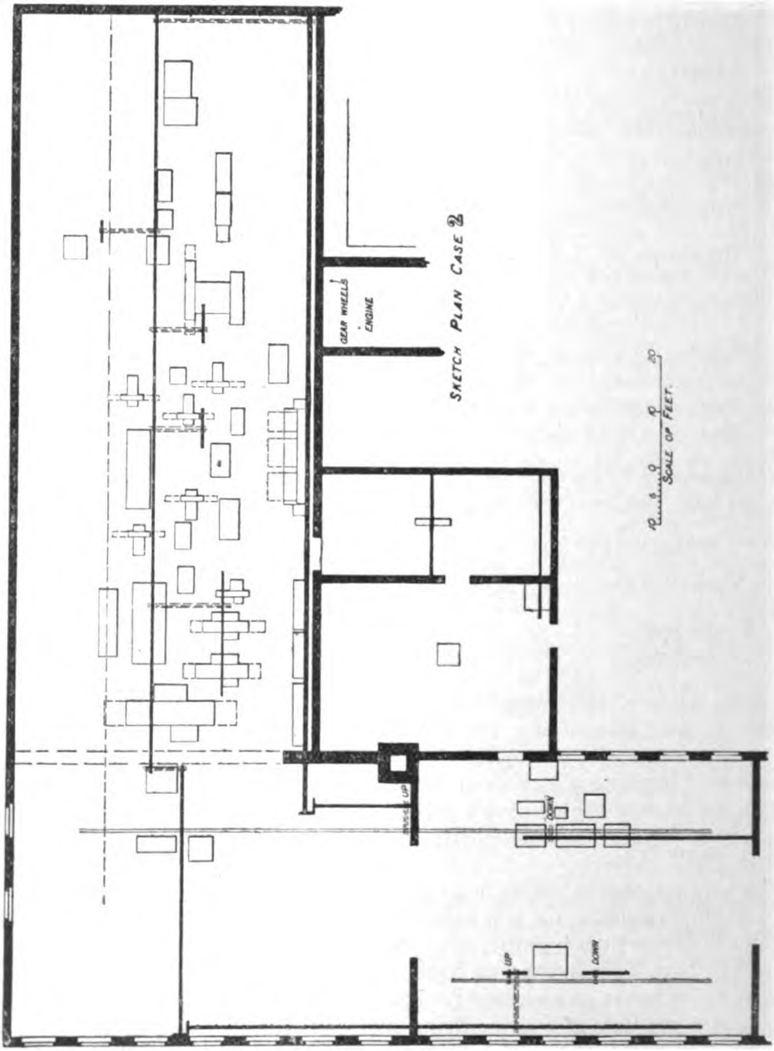


FIG. 2.

Ground-floor Shafting shown solid. Countershafts omitted.
First-floor Shafting shown in outline.
Drives from Shaft to Shaft shown thus

Mean load	26·6 I.H.P.
Max. „	34–40 „
Engine and shafting friction	22 „
Mean useful load	4·6 „

with the same assumption as before with regard to the power absorbed by loaded shafting.

The coal bill was about £430 per annum, and the total engine costs something like £600, or about £22 per I.H.P. per annum, exclusive of rent, rates, taxes, insurance, interest and depreciation.

Observations were made over some weeks in order to determine the actual intermittency of the tools, with the following results :—

Motor Groups. See page 979.	Class of Machine or Group.	Max. B.H.P. required for Group.	Per cent. of time Group Shaft would run.
1	Plate stretching rolls	6	20
1	Saws...	3	40
1	Drilling machines	$1\frac{1}{2}$	45
1	Milling and slotting machines ...	6	70
1	„ „ „ ...	6	90
1	Small planing machines	6	60
1	„ „ „ special ...	4	60
1	Large „ „	6	70
2	Lathes	$1\frac{3}{4}$	50
1	Sheet metal machines	6	14
1	„ „	4	36
1	Brass-finishing machines... ...	$\frac{3}{4}$	40
1	Odd brass machines	$\frac{3}{4}$	10
1	Small special lathes	$\frac{3}{4}$	15
1	Polishing laps and brushes ...	4	50
	Drilling machine	$\frac{3}{4}$	60
	„ „	$\frac{1}{2}$	50
	Small machines	4	60

The shafting load estimated from an empirical formula, taking into account diameter, length, speed, number of bearings, and number and width of belts, is—

Diameter.	Length.	B.H.P. hours per 3,000 hours.
Inches.	Feet.	
3	135	11,880
3	4·1260	1,260
3	4	1,449
2	22·5	1,530
4	140	18,770
2	22	2,220
2·25	152	4,860
2	222	7,290
		49,250 ≡ 16·4 B.H.P.

a figure which agrees very closely with what one would expect from the indications of the engine.

Taking the shafting load at this figure, and the useful load at the I.H.P. given by the engine, viz., 4·6 H.P., the cost of driving by a single 40 H.P. motor works out at £264 12s. 6d.

	£	s.	d.
10 per cent. on installation	28	0	0
Brushes and cleaning	5	10	0
Current	231	2	6
	£264	12	6

As a matter of fact the drive is being divided over four motors; with what object the author fails to understand, since almost the whole of the shafting is to be driven and no one of the advantages of electric driving is to be secured.

The cost of driving in this way will be greater than that shown by the single-motor arrangement. The estimate being—

	£	s.	d.
10 per cent. on installation	40	0	0
Brushes and cleaning	11	16	0
Current	239	17	6
	£271	13	6

Case III.

The shop here taken as an example (see Fig. 3), unlike those already given, has only been erected a few months, and it had already been decided to drive with current from the Corporation mains; yet in spite of this, the same want of intelligent appreciation of the conditions of the problem are shown.

The works, as will be seen from the plans, consist of two shops one over the other, and a moulding shop. The lower shop contains a small planing machine, slotting machine, shaper, drilling machine, grindstone, and several lathes, one only of which is in fairly constant use.

The business carried on is chiefly that of brass finishers, although all sorts of repairs are done.

In the lower shop it is rare for more than one or two tools to be working at one time, and more often than not only one lathe is in use.

The lower shop, of which we are at present speaking, is driven by a 5 H.P. motor, driving by belt on to a short shaft and thence by belt on to the line-shaft running the length of the shop. The shafting is of steel, and is run in self-adjusting bearings. It has been most carefully installed, and absorbs little power; with seven belts to counter-shafts, including the driving of the loose pulleys this amounted to 1·05 B.H.P. The motor, however, although by a well-known firm, absorbed 2·65 E.H.P., running entirely light at the time the experiments were made; this has since been reduced to 2·47 E.H.P. by an alteration of the maker's adjustment of the brushes. The result is still not what ought to be expected by a very long way.

The upper shop contains several small lathes and other small tools.

and it may be taken that three or four tools are as a rule in operation: there are also a set of polishing brushes which run a small part only of their time, and are driven independently by a separate motor.

The main drive in this shop is by a 6 H.P. motor belt connected to a line-shaft.

This motor when driving only the shaft, belts, and loose pulleys absorbs 2·47 E.H.P.

The author has had observations made as to the time which the motors ran: during the period of observation the polishing motor was entirely idle, that in the lower shop ran 22·75 hours per week of 53 hours, the top shop motor running full time.

This gives us a consumption of 160 units for driving shafting; the meter readings gave a total consumption of 174 units during the 53 hours: thus the energy actually used usefully was 14 units, equivalent to a mean useful load of ·36 E.H.P., or about 8 per cent. of the total.

The annual cost on the assumption that the conditions obtaining during the period of observation are maintained during the year will be—

	£	s.	d.
10 per cent. on installation	12	0	0
Current	56	0	10
	£68	0	10

These figures are exclusive of the cost of running the polishing brushes and a small motor recently erected in the moulding shop.

As the improvement in the efficiency of the 5 H.P. motor is directly due to the measurements taken by the author for this paper, it has not been considered in the above figures, since there is no doubt that it would under ordinary circumstances not have been made.*

Probably there is no problem in the everyday practice of engineering which involves so many factors that can only be ascertained by tedious observation in each case, or where this work is so amply rewarded. Experience is no doubt of very great value, but if any one, however experienced, shirks the trouble of making the observations which have been referred to, the results which he will achieve will fall far short of success.

In the early part of this paper certain general lines were laid down, but it will be found in practice that those conditions are frequently incompatible, and the engineer, as in so many other cases, must make a compromise.

It is seldom that all the advantages of the electric drive can be secured in any particular instance, but with care those most essential to any particular class of work may be obtained without too much complication or loss of financial efficiency.

The possible advantages are:—

1. Reduction of waste load.
2. Positions of machines independent of shafting.
3. Speed of individual machines or groups independent.

* Since this paper was written the makers have been communicated with, and at once offered to replace the motor by a thoroughly efficient one.

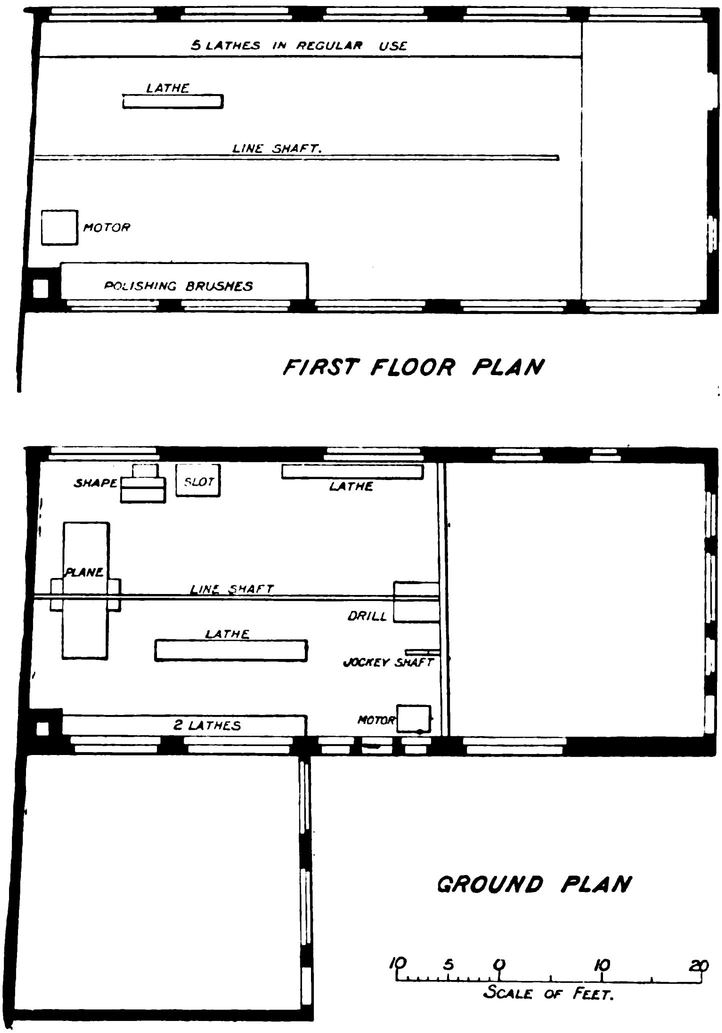

5 LATHES IN REGULAR USE
LATHE
LINE SHAFT.
MOTOR
POLISHING BRUSHES
FIRST FLOOR PLAN
SHAPE
SLOT
LATHE
PLANE
LINE SHAFT
DRILL
LATHE
JOCKEY SHAFT
MOTOR
2 LATHES
GROUND PLAN
10 5 0 10 20
SCALE OF FEET.

FIG. 3.

4. Facility for using portable tools or magnetic chucks.
5. Convenience on occasional overtime.
6. The very partial nature of a breakdown and rapidity of repair.
7. Advantages connected with travelling cranes.
8. Absence of strains in roofs and consequent cheapness of construction.
9. Facility with which power measurements may be made.

The importance which attaches to the reduction of waste load depends largely on what is in the particular shop the original source of power. If current is generated by the use of steam engines on the premises, the saving made by reducing waste load is not at all proportionate to the reduction of the load, as a large part of the cost of generation is due to charges which do not increase in proportion to the load: when, however, current is obtained from an outside source at a practically level rate, this reduction becomes of very great importance.

In being able to place his machines so that they get the best light, and so that as little as possible need be wasted in getting work to or from them, the works manager is in a position to demand the maximum both as regards quantity and quality from his men; and he can see at a glance whether or not machines are being kept in that state of cleanliness which is essential if good work is to be done and if machines are to depreciate little.

The advantages due to the control of the speed of individual machines, both in improving the quality of the work and in increasing the quantity turned out, have not been fully appreciated up to the present; speaking as a practical turner who has had experience of both systems of driving, the author is in a position to say that not only can better work be done but a very great deal more of it on a lathe fitted with a separate motor and a shunt regulating resistance. It is perhaps somewhat rash to estimate the extra output under this heading, but on lathes and planing machines which are not doing repetition work an increase of anything between 20 per cent. and 40 per cent. is usually obtained.

There are two ways in which portable tools may be of very important use: the first when the piece to be machined is of great weight in proportion to the amount of machining to be done on it; and the second when several parts of the piece may be machined simultaneously so that time may be saved.

It is not necessary to speak of the advantages pointed out as Nos. 5, 6, 7, 8 above, as these are either sufficiently well known or are obvious.

It may be pointed out that the possibility of the easy, rapid, and accurate measurement of power which is afforded by electric driving is valuable to the works manager, firstly, because the friction load of a machine is a very reliable indication of the condition of the machine, both as regards its cleanliness and its adjustments; and secondly, because the current consumption as given by a meter shows very clearly whether or not the machine is being worked up to its full capacity or not.

The smallest size of motor which it is ordinarily desirable to employ depends to a large extent on "the taste and fancy" of the engineer; the voltage of supply, however, seems to fix the limit in ordinary cases: the author does not hesitate with a pressure of 200–250 volts to employ motors as small as 1 H.P., and where any great advantage is to be secured thereby, motors of ¼ H.P. It must not, of course, be lost sight of that small motors are less efficient than larger sizes, and that therefore they should only be used where the saving or convenience which can be secured by them outweighs their disadvantages and leaves a large margin of benefit.

The general arrangements as to the number of motors used with which the author is acquainted are:—

1. One motor per works: This replacing of a steam or other engine by an electromotor is, to say the least of it, foolish, as a gas, oil, or steam engine would always give a more economical and equally satisfactory drive.

2. One motor per tool: This arrangement is, as a rule, not the best, as although the cost of the current is reduced very greatly, it is at the expense of interest and depreciation, and it is difficult to imagine an engineering shop where all the tools would be benefited by speed control other than that obtained by cones, etc., or where many tools at any rate are not employed on standard work which enables them to be grouped without loss of efficiency.

3. One motor per line-shaft: This arrangement leads to a certain amount of economy in large works generating their own current, but is decidedly bad where current is purchased at an approximately level rate, as the substitution of oil or gas engines would give a still more economical drive. In either case the advantages peculiar to electric driving are not secured.

4. Mixed arrangement developed from No. 3: In this arrangement one motor per shaft is employed as far as possible without involving long lengths of idle shafting, and a few tools may have separate drives on account of their inaccessibility.

5. Mixed arrangement developed from No. 2: This arrangement, which appears to the author to be the only reasonable one, may be described as one in which each tool having a large percentage of idle time, or which would benefit by a variable-speed control more delicate than that given by the usual mechanical means, has its own motor, and the remainder are grouped, not in any hard and fast way as so many tools per motor, but in larger and smaller groups in such a way that the sum of the interest, depreciation, attendance, repairs and current cost shall be a minimum.

Probably the best way of arriving at the arrangement last described is to pick out those machines which require separate motors in order to secure variable speed, then those which are idle for a large percentage of their time, as it will very likely be possible to group some of these without loss; the remainder of the tools will very probably fall into convenient groups, but if not, their grouping merely involves the calculation of the cost of driving for two or three arrangements.

In grouping it should always be borne in mind that it is often

possible to combine tools to form a group so that the shaft driving the group need only run a proportion of the working hours of the shop. Sometimes one man has a group of machines in his charge of which only one or two run at any moment : a group is thus formed naturally, and may be driven by a motor too small to drive all the machines of the group at once.

There is no doubt that the more the drive is split, the greater will be the total H.P. of the motors required, and so the capital cost, for the help given by the inertia of the shafting, etc., to reversing machines and to those liable to sudden variations of load, is reduced, and the

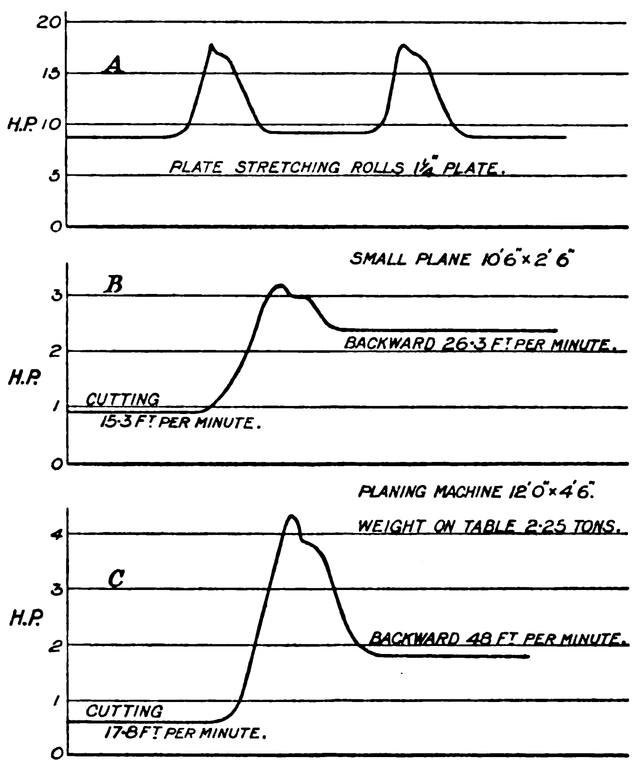


FIG. 4.

fact that a large number of machines having a variable load never synchronise is also neglected.

The total power of motors required with a divided drive such as has just been indicated will of course vary very greatly in different shops, probably as much as from twice to five times the maximum useful load of an engine driving the same shop.

The power absorbed by particular machines can only be ascertained by actual measurement, the power stated by tool makers being some-

times many hundred per cent. wrong. The few powers given below have been measured by the author on tools in actual work under ordinary shop conditions :—

12 ft. × 4 ft. 6 in. planing machine...	Diagram C. (Fig. 4).
Radial drill, holes to 1¼ in.	¾ H.P.
6 ft. × 30 in. planing machine ...	2·65 H.P. in reversing.
10 ft. 6 in. × 30 in. planing machine	Diagram B. (Fig. 4).
Lathe 5½ in.	Up to ·34 H.P., cutting heavy screw.
Lathe 9 in.	·5 H.P. chasing thread on 2¼ in. gas-pipe.
Drilling machine, holes to ¾ in. ...	¼ H.P.
Plate stretching rolls	Diagram A. (Fig. 4).

The connection between the tool and the motor is at present receiving a good deal of attention, especially at the hands of American tool builders, and large numbers of tools are being built with a motor as

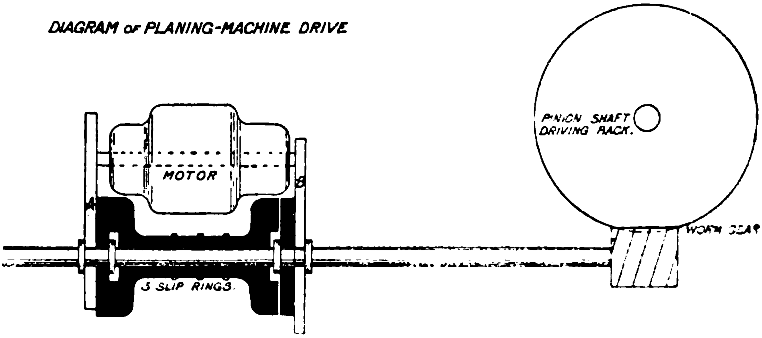


FIG. 5.

The magnetic clutch (solid black) is double-ended and slides on the worm shaft with a float key. In the position shown, the train of gears A is connected to the shaft by the clutch, which is in contact with the left-hand armature. The gear train contains an idler—on the current being passed (by the machine tappets) through the other end of the clutch, the latter slides into contact with the armature attached to gear train B.

a part of the construction. But in dealing with old shops, the connection whether to group shafts or to individual tools has to be provided; more often than not without any serious stoppage of the work : in these cases a belt connection to the group shaft, or to the existing countershaft of the machine, will as a rule be found the most convenient, though a raw-hide pinion and a spur wheel or worm gearing can sometimes be employed and are to be preferred.

There are, however, two classes of machine to which special connections should be fitted, namely, machines which reverse periodically and have large inertia, such as planing machines; and machines of very great inertia which absorb a very large power in starting, yet take comparatively little power in running.

A most ingenious arrangement for driving the former class of machines is already on the market, and the author believes is working perfectly satisfactorily, the only objection to its adoption being that the price is extremely high and is certainly not warranted by the cost of manufacture. A diagram of this appliance is shown in Fig. 5.

The second class of machines which should have special attachment is represented by the grindstone used in many works for removing scale from bars, dressing of rivets, and for other purposes; these stones vary in size, but are usually about 7 feet diameter when new. Such a stone absorbs, with the friction of its bearings, from 2½ to 4 H.P., and occasionally for short periods as much as 5 H.P. after it gets up speed, so that a motor of 4 H.P. is amply sufficient to drive it, but it requires one of at least 15 H.P., even when a few series turns are provided, to start it if both have to start together; and if the motor is allowed to get up speed and the stone then coupled by anything approaching a rigid connection, the motor, even if of 15 H.P., is extremely likely to be injured, as it will be overloaded to an enormous extent.

To meet these difficulties and to provide for a constant peripheral speed in spite of the wear of the stone, as well as for a low speed of about 50 linear feet per minute when turning up, the author has proposed a two-speed motor with a small controller and a shunt regulator driving the stone through a belt, and the use of a magnetic coupling in the shaft which carries the stone, or, if possible, in the motor shaft between the motor and the pulley. The current supplying the clutch passes through a rheostat, so that the power transmitted to the stone is under control.

The method of operating this apparatus is extremely simple; the controller is turned to one or other of its two positions according to the diameter of the stone, and the motor switch pulled over slowly just as in starting a motor, but after the motor has acquired its speed the switch is carried on, cutting out resistance in the clutch circuit and so gradually transmitting more and more power to the stone. The advantage of such an arrangement is that the stone can safely be started by a motor no larger than is necessary to drive it, and no excessive current is called for. There is, of course, the advantage also that the stone can be driven at the best peripheral speed irrespective of its diameter.

The above arrangements have been described at some length and illustrated, not entirely on account of any merit which they possess, but because the solution of every such problem is a help in the solution of other problems, and many difficulties in the electric driving of machine shops have still to be met and overcome.

It may be remembered that a small flywheel on the motor shaft, and a few series turns on the field, are frequently a great help in dealing with a load such as a planing machine.

Returning now very briefly to the three cases of which particulars have been given, and planning out the installations on the lines which have been sketched, we shall see that very appreciable savings can be effected, and all the advantages due to the electric drive secured.

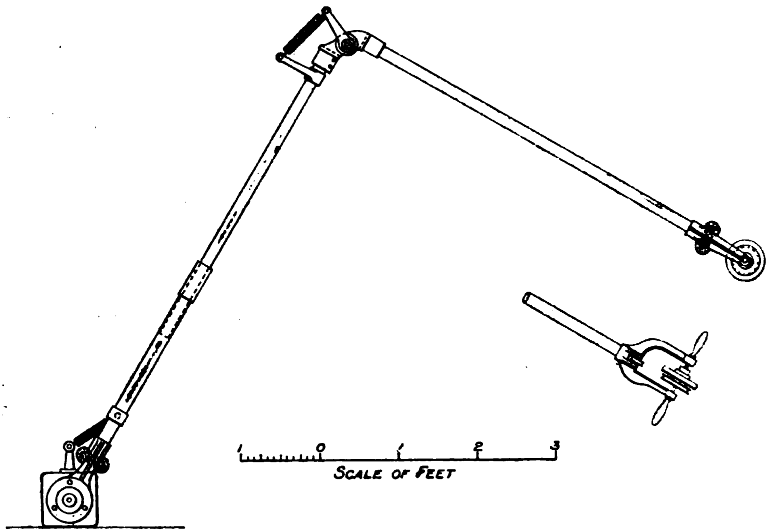


FIG. 6.—Portable Electric Grinder, for dressing seams and rows of rivets in plate-work, Motor on floor driving wheel by twisted leather belt inside tubes.

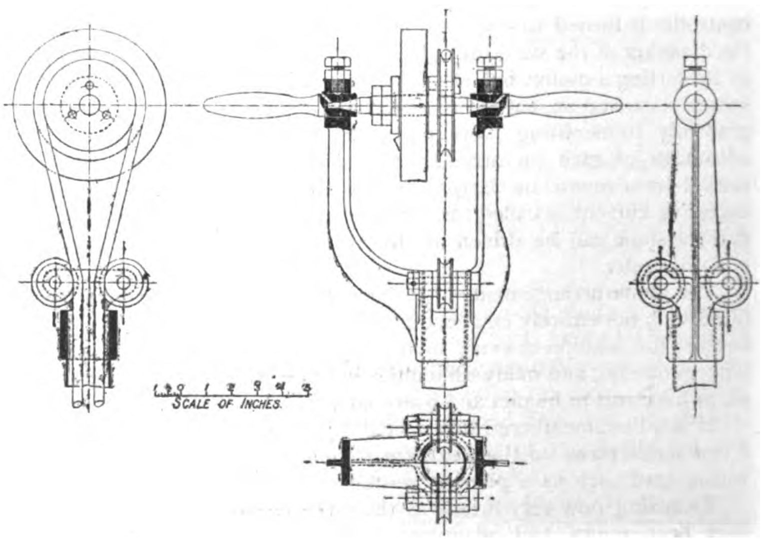


FIG. 7.—Portable Electric Grinder—Details of Head.

CASE I.

This case does not lend itself very well to much grouping, those which appear to be advisable being a small group on the lower floor and one on the upper. These would consist of five tools each. The installation would then require fourteen motors ranging in size from $1\frac{1}{2}$ to $7\frac{1}{2}$ H.P., and averaging 2·8 H.P.

The cost of running, based on the same period as that already given, would be—

	£	s.	d.
10 per cent. on installation	34	0	0
Cleaning	7	10	0
Brushes	6	0	0
Current	44	3	10
	£91	13	10

as compared with £186 7s. 2d. with the single-motor arrangement.

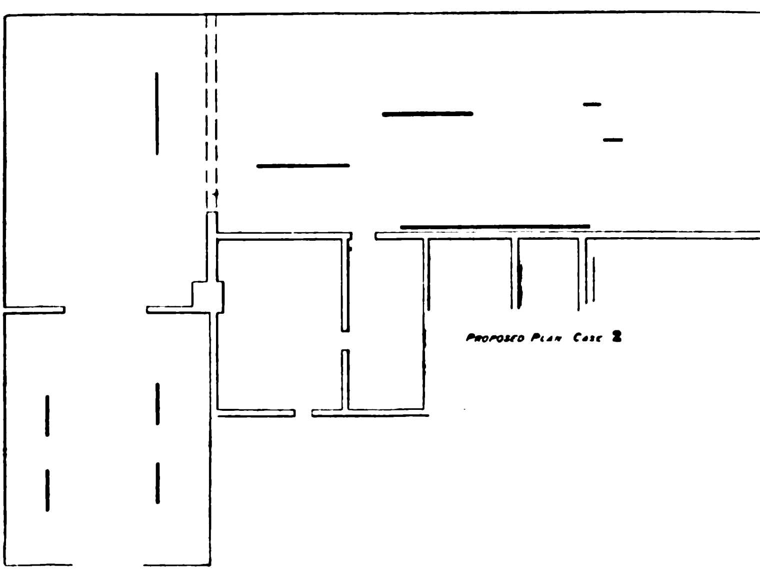


FIG. 8.—All Shafting shown solid.

CASE II.

In this case individual speed control can be obtained in every case where it is of very great value, and all awkward drives avoided without the use of a large number of motors; at the same time the dead load can be reduced to the equivalent of 3·1 H.P.

The number of motors would in this case be eighteen, ranging from $1\frac{1}{2}$ to 6 H.P., the grouping being indicated in the table on page 969.

The cost of the installation would be £700, and the running costs on the basis previously taken.

	£	s.	d.
10 per cent. on installation	70	0	0
Cleaning and brushes	26	0	0
Current	95	7	8
	£191	7	8

as compared with £264 12s. 6d. with the single motor.

Case III.

By dividing the shaft in the upper shop into two, and adding separate motors for the planing machine and the principal lathe in the lower shop, the average dead load could be reduced to 1·86 H.P.

The current consumption per 53 hours would be reduced from 174 to 85 units, of which 16·5 per cent. would be usefully employed.

The running costs for the year would now become—

	£	s.	d.
10 per cent. on installation	19	4	0
Current	29	3	4
	£48	7	4

as compared with £68 0s. 10d.

It is not at all an easy matter to institute any general comparison between the costs of steam and electric driving, but it is possible to suggest certain approximate formulæ which may be of use in arriving at a rough approximation.

The cost of steam driving depends chiefly on the size of the plant and on the ratio which the mean load bears to the maximum, and may be expressed by—

$$A + Bp + Cr,$$

where A B C are constants expressed in £ per annum;

p is the maximum I.H.P. of the engines;

r is the mean I.H.P. taken over the year.

A represents wages in looking after boilers, engines, shafting, and belts.

B is interest, depreciation, rent, repairs.

C is coal, oil, and stores.

The following values have been obtained in a few cases :—

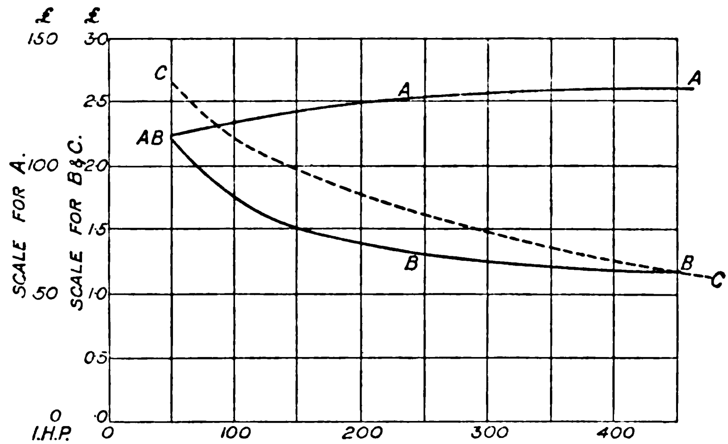


FIG. 9.—Annual Cost of Steam Power. Value of Constants.

In an engineering shop of reasonable size, it is to be remembered that the maximum load is always large compared with the mean.

Taking the case of an engine of 125 I.H.P., we get from the formula and the "constant" curves already given the following curve giving the relation between the ratio maximum mean load and the annual cost.

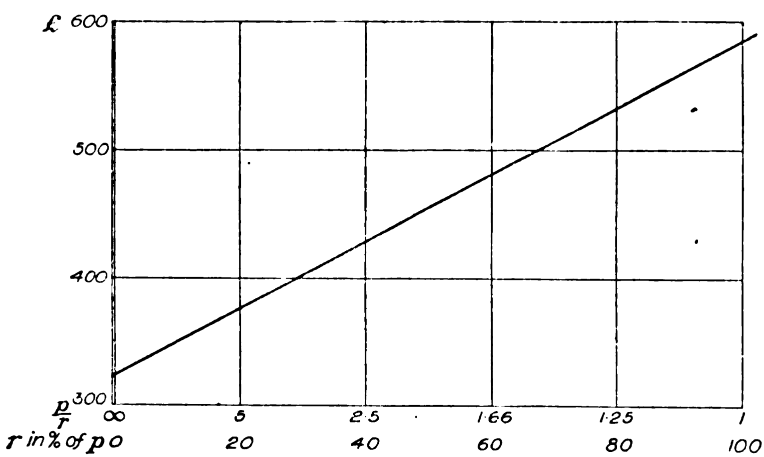


FIG. 10.

The cost of motor driving may be given by a formula of the same form as that for steam driving—

$$A' n + B' p' + C' r',$$

where—

A' is cost of wages in attending to motors, shafting, and belts per motor.

n is number of motors.

B' is interest, depreciation, repairs.

p' is total B.H.P. of motors installed.

C' is annual cost of one B.H.P. in £.

C' is given by—

$$\frac{1}{e} \times \frac{746}{1000} \times \frac{x}{240} \times \text{hours of running} \times r',$$

where e represents the efficiency of the cables and motors as a fraction of unity;

x the cost of current in pence per unit;

r' the total mean load taken over the year.

The constants in the above expression are given for a few cases by the following curves:—

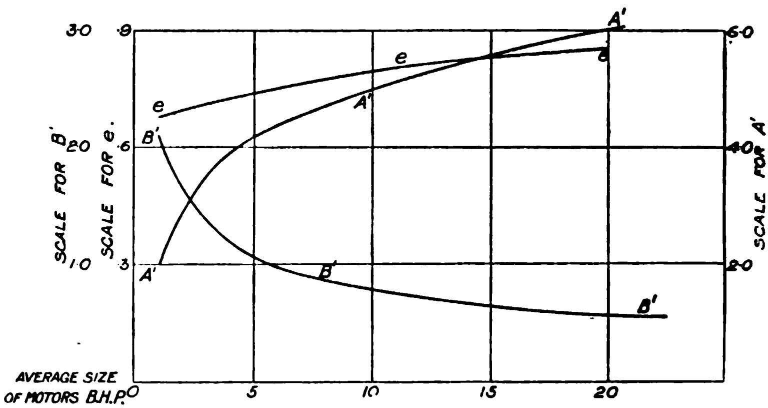


FIG. 11.—Annual Cost of Motor Distribution. Value of Constants.

Taking now a case for comparison and letting the data be as follows:—

$p = 125.$ $\quad r = 50$

$n = 25$ $\quad p' = 100$ $\quad x \doteq 1\text{d}.$

giving C' 11·28,

we get r' 18·3 by equating the steam and electric costs, which shows us that under the assumed conditions if the mean useful load, together with the average load of such shafting as may be used for grouping, is less than 18·3 H.P., the electric is cheaper than the steam drive.

The formulæ given above are not intended to be anything more than suggestions on which each engineer may build similar formulæ by the substitution of constants suitable to the conditions which prevail in the district and in the class of work with which he may be connected.

It would be outside the scope of the present paper, which is intended to deal rather with the use of electricity, to enter into the question of its economical generation ; but the author would like, before closing, to express the opinion that, unless the saving to be gained by generation on the premises is considerable, it is wiser to procure current from an outside source and so take advantage of the reserve plant of a central station, and at the same time be entirely free to devote one's attention to one's own particular business rather than for the sake of a small apparent saving enter into the business of electrical supply with its responsibilities and troubles.

If, however, current is generated on the premises, it must not be forgotten that the use of batteries may, owing to the large fluctuations of load, be productive of considerable economy.

In conclusion, the author would point out that the subject on which he has been speaking is a very wide one, and one bristling with difficulties owing to the limited amount of experimental work which is available, and that therefore he can only hope that the paper will be useful rather as a collection of suggestions than as anything more ambitious, and that it may in some small degree help to the intelligent appreciation of the problems involved in the application of motors to machine shop driving.

The PRESIDENT : The Council thought that it might be desirable to have the two papers read at the same meeting, so that the discussion might be had on the two papers together. Of course at this late hour it would be quite unreasonable to start a discussion on these valuable papers, and therefore, I presume, we will adjourn the discussion to the the next meeting.

The PRESIDENT announced that the scrutineers reported the following candidates to have been duly elected :—

Members.

Frederick Giffard Cole. | Dr. George Finzi.

Associate Members.

Chas. Frederick Butler. | Robert Walter Grubb.
Harold Edward Donnithorne. | John Hayward Home.
H. P. Prior.

Associates.

John Norman Alty. | Edmund Davidson.
Gwylim Anwyl Hughes.

Students.

Walter Charles Lambourn. | Wm. Stanley Lonsdale.
Donald Grant Tyrie.

The Three Hundred and Ninety-fifth Ordinary General Meeting of the Institution was held at the Society of Arts, Adelphi, on Thursday evening, May 14th, 1903—Mr. R. K. GRAY, President, in the chair.

The minutes of the Ordinary General Meeting of May 7th, 1903, were, by permission of the meeting, taken as read, and signed by the President.

The names of new candidates for election into the Institution were taken as read, and it was ordered that they should be suspended in the Library.

The following list of transfers was published as having been approved by the Council:—

From the class of Associate Members to that of Members—

Gerald Henry John Hooghwinkel.

From the class of Foreign Members to that of Members—

Guido Semenza.

From the class of Students to that of Associates—

James Hally Brown. | John Blundell Butler.
Frank Knight Jewson.

Messrs. I. W. Chubb and J. Fiddes-Brown were appointed scrutineers of the ballot for the election of new members.

Donations to the *Library* were announced as having been received since the last meeting from the Astronomer Royal, Messrs. A. H. Jackson, H. M. Leaf, and the Maschinenfabrik Oerlikon; and to the *Building Fund* from Messrs. S. V. Clirehugh, W. J. Cooper, and W. McGeoch, to all of whom the thanks of the meeting were duly accorded.

The PRESIDENT: Before beginning the discussion, I have to announce that the Council this afternoon, believing that it would meet with the general approval of the members of the Institution, have decided that the Annual General Meeting should take place at the new offices. We thought this arrangement would give an opportunity to the members to see the new offices, which will be found spacious and commodious: it was also thought that the convenience of members would be better met if the hour were changed from 8 p.m., which is the usual time of our General Meetings, to 5 o'clock in the afternoon. You are aware that we are debarred from having any technical paper read at those meetings, and it appeared to be superfluous and to cause unnecessary inconvenience to bring people together in the evening at 8 o'clock to hear read the Annual Report of your Council, which

contains matter of which to a great extent the members are already aware.

I have no doubt, gentlemen, you will confirm the Council's decision.

RESUMPTION OF DISCUSSION ON PAPERS BY MR. A. D. WILLIAMSON, ON "APPLICATIONS OF ELECTRICITY IN ENGINEERING AND SHIP-BUILDING WORKS," AND MR. A. B. CHATWOOD, B.Sc., ON "ELECTRIC DRIVING IN MACHINE SHOPS."

Mr. H. A. MAVOR: I am glad to have an opportunity of expressing my thanks to Mr. Williamson for this paper. It is one of the most useful and practical papers that we have had before us, and one that lends itself to useful discussion. There are some points in it which, with your permission, I would like to emphasise. We have on page 930 an interesting table of Works Costs. I have taken the opportunity to compare these costs, not with those of other electric installations, but with an entirely different group of costs. Mr. Mavor.

It has always seemed to me important in considering the costs of electrical production, more especially in factories, that we ought to place ourselves, not only on all fours with what we and our friends in the same business have been able to do, but with what is being done in other regions. I happen to have a pretty complete tabulated record (Table I.) of a group of costs taken from different parts of the country and over widely different industries; and I have found it interesting to compare these costs with one another. For the sake of convenience I have reduced them to terms of cost per unit, by translating the indicated horse-power into units by taking 600 watts per I.H.P.; and also for convenience I have translated the coal into a uniform price of 100d. per ton, which is a convenient figure for calculating, and not very far from about the average cost over the country. That works out to 0·045d. per lb. Having the figures in that form, it is easy to see how many pounds of coal are being used per killowatt or per horse-power as the case may be. I find that the best kind of business for economical power production is to be found in weaving and spinning factories. Flour mills are nearly as good; and the very worst and the most expensive power production in the whole range of British industry that I have been able to find is in engineering workshops. That is not difficult to explain, and it is interesting in this connection, because we are here dealing with an engineering workshop. It is pleasing to find that in this workshop the costs of power production are not hopelessly bad; but they are a good deal worse than the best, and that is the point that I wish to call attention to. I have eliminated from the comparison the repairs and the cost of water, because they may vary under widely differing conditions; and as the depreciation figures in this paper are not given in detail, I think that it would be well also to eliminate them. I have made a very simple comparison between the best record I have of power cost—it was a spinning mill in Lancashire—and the two first cases which are given in some detail on pp. 930 and 931 of Mr. Williamson's paper. The most startling difference is in the wages per unit. This is

Mr. Mavor.

TABLE I.

1897. Result of Inquiry into Cost of Power Coal. Price Corrected to 100 Pence per Ton, ·045 Pence per Lb.

Class of Factory.	Hours per Annum.	I.H.P. Hours in Thousands.	Coal Weight in Thousands of Pounds.	Coal per I.H.P. Hour in Lbs.	Coal per I.H.P. Hour in Pence.	Wages per I.H.P. Hour in Pence.	Oil and Stores per I.H.P. Hour in Pence.	Total Cost per I.H.P. Hour in Pence.	Per Unit.
Weaving	2,888	2,550	6,450	2·5	·112	·013	·011	·136	·227
Spinning	2,800	2,350	5,250	2·25	·1	·02	·012	·132	·220
"	2,850	640	1,740	2·72	·122	·04	·013	·175	·292
Flour	5,500	1,920	5,000	2·68	·12	·036	·013	·169	·282
Engineering	2,700	360	1,720	4.8	·214	·068	·013	·295	·492
Corn Mill	6,000	2,160	4,350	2·0	·09	·043	·012	·145	·242
Thread...	2,800	15,300	55,000	3·5	·156	·025	·01	·191	·320
Tweed	2,900	1,000	6,000	6	·27	·073	·014	·357	·595
Paper	7,312	5,120	25,500	5	·222	·025	·01	·257	·43
"	7,200	2,400	11,200	5·65	·207	·04	·015	·262	·437
Chemical	6,500	2,400	12,200	5	·222	·02	·002	·244	·407
Paper	6,700	4,690	18,000	3·85	·172	·032	·01	·214	·357
Engineering	2,808	200	5,570	27·85	1·25	·18	·03	1·46	2·433
"	3,100	540	10,000	18·5	·825	·09	·03	·945	1·575
Sugar Refining ...	6,900	320	4,500	14	·625	·16	·012	·797	1·33
Paper	7,000	6,300	31,000	4·9	·22	·052	·011	·283	·472
Shipbuilding	2,650	530	8,200	15·4	·69	·154	·08	·924	1·54
Electrical Engineering	—	—	—	—	—	—	—	·503	·838
Chemical	—	—	—	—	—	—	—	·18	·3

Mr. Mavor.

a point which I think deserves our most careful consideration. We are quite accustomed to trust our lives in trains running at sixty miles an hour, with a man of the working class and a stoker looking after the engine, which may be of a thousand horse-power. I think you will find it not a very difficult calculation to ascertain how much that runs out per horse-power per hour. It is not much; it is not anything like a tenth of a penny per unit. The best record that I have been able to get of actual results from year's end to year's end in wages is the equivalent of 0·022d. per unit in a spinning mill which also has a very low consumption of coal. To-day I took the opportunity of going through the valuable tables in *Lightning* for power productions. I am very much surprised to find that one of the cheapest power-stations is in London—Westminster, which is 0·16d. per unit, Bradford and Edinburgh being each 0·09 per unit. Each of these latter is four times as high as it is in the spinning mill. Those of us who are familiar with the conditions of working in such factories, where power is a very important element in the prime cost, and where consequently it has been carefully sought to reduce it to its lowest figure, know that the conditions there are very different from what they are in an electric generating-station. I think it is time that we electrical engineers should realise that it is not necessary to have expensive labour for looking after electric machinery. If we do not believe it, then users of electric machinery are not likely to be convinced that they can dispense with expensive labour. I am glad to find that Mr. Williamson has grasped this point. I do not offer this by way of criticism, but for the purpose of emphasising what, among the multiplicity of other matters, he has not been able to so fully call attention to. I think that it is this very point of labour cost which leads Mr. Williamson to recommend large units running at slow speed.

Larger units would necessarily result in a very great difference in coal economy. In fact there is considerable room for coal economy in the cases under consideration as compared with the spinning mill I have been referring to. The cost, correcting the price of coal to 100d. per ton, is 0·168 per unit at the mill, as against 0·27 in works (*a*), and 0·29 in works (*b*). I may incidentally point out here that I do not quite understand Mr. Williamson's comparisons. He says there is a difference of the tenth of a penny. I think that is largely due to coal being cheaper in the second works. The actual saving appears to be about the half of that, when the coal is reduced to a common figure for cost.

The use of low-speed units is another important point which I should like strongly to advocate here. Those of us who are building dynamos know that the attention which a dynamo requires is entirely at the commutator, and that if you have a high-speed commutator, there is necessity for frequent adjustment and attention from the attendant; and that as our units increase in size, we ought, if we use high-speed engines, to keep the commutators as small in diameter as is consistent with proper working, and have the surface speed as low as possible.

Then Mr. Williamson recommends an increase of voltage. It is easy when one looks over an installation of this kind, with over

Mr. Mavor. 10,000 horse-power, to say what a pity it was not begun on better lines; but we must not forget that experience has to be gained, and experience here thoroughly confirms what one would expect, namely, that higher voltage and the three-wire system would be recommended for future extensions, as Mr. Williamson mentions. I think one of the most important features in the improvement produced by the use of bigger units, is the abolition of the switchboard with all its complications. The abolition of compound winding is a natural consequence of the increase of size, because the percentage drop on big units is much less than the drop on small ones. With big units there is no necessity for any switchboard at all. Switches for heavy currents are very ornamental and expensive; but every one knows that the last thing one thinks of is to switch off the heavy currents at the switchboard. Those switches are never used, and therefore ought not to be there. The abolition of the switchboard abolishes the switchboard attendant and his cost. One point I would like to ask Mr. Williamson is, Can he give us any record of the breakdowns that have taken place, and the nature of them? He mentions that the engines when opened out show very little wear on the cylinders; but what about the valves, and what number of breakdowns have been recorded in the course of working? I expect that his answer will be that they have been extremely small. I wish to use this as an argument for reducing the number of units; we only have one engine on an express train; we have very many steamers crossing the ocean with only one engine—at most two; and therefore it does not seem as if there was any sense in having five or six units in a power-station. On page 935 of his paper, Mr. Williamson very rightly points out that the varying methods of applying motors to machines do not in themselves result in great differences in economy. The real point is that, after all, electricity is only a means of distributing power, and that economy is to be got in the generating station. The loss in shafting is frequently very high, but I do not think we always remember that the interest on the cost of the electric plant is also high. The real argument for adopting electric drive is the possibility of introducing economical plant into the generating stations. Then with regard to the speed, weight, and price of motors. If I may be pardoned for introducing a personal suggestion of my own here, I think that if we want slow-speed motors, we cannot do better than turn them outside in—put the armature outside the magnet, and you at once get a very high speed for the wires on the rotor of the machine—a high peripheral speed without a high rotative speed. The difficulties of lubrication have been solved and there is not any difficulty left. Some of the older members of the Institution will remember that there was a machine in the very early days in which there was a fixed internal magnet—the Elphinstone-Vincent machine; that is capable of development in a very satisfactory way. I had the pleasure of showing last year at the Institution of Civil Engineers a motor constructed on this principle, which gives exceedingly low speed with a very small size—a one horse-power motor, at 500 revolutions, only a foot in diameter and a foot long.

Mr. Selby Bigge. Mr. D. L. Selby Bigge: I have read this paper of Mr. Williamson's

Mr. Selby Bigge.

with the very greatest interest. For the past fourteen years I have been engaged in the work upon which Mr. Williamson touches—that is, the application of electric power to the driving of works and different industries. I think that this paper is of the very greatest value. It is practical and sound from beginning to end. The points that Mr. Williamson brings forward, as he says, are facts within his own experience, and they should carry great weight, I think, with the members of this Institution. All the points that he brings forward most thoroughly corroborate all the statements that other writers on this subject have put forward; in fact, my views so thoroughly coincide with those of Mr. Williamson upon those points, that it is very difficult for me to criticise what he has said. In going briefly through this paper I find, looking at page 926 in the first instance, that Mr. Williamson has had to deal with works which have been gradually growing, and it has been very difficult for him from the outset to formulate a scheme for the whole of those works. I have always found that it is of the very greatest importance when considering a scheme for a works to take the whole of the works into consideration from the outset, and as far as possible to take all possible extensions into consideration; and when you have arrived at the whole of the power that the works are at the present time using, and what they are likely to use in the future, then total that power up. Supposing that the power amounts to 2,000 or 1,500 horse-power, for the sake of argument, you then immediately split up that power into certain fixed units; and I think that the greatest economy can be derived from the plant in which there are never more than two units working at the same time. That to a certain extent bears out what Mr. Mavor has just now said on the subject of large units and in favour of having few units working; but I can fully appreciate the great difficulty in Mr. Williamson's case that he had in that direction. I had the pleasure of visiting Messrs. Vickers-Maxims' works, when Mr. Vickers showed me all round the works at Sheffield, so that I have some slight knowledge of the conditions that Mr. Williamson had to tackle. I must say that the result has been most satisfactory. In the case of the engine-works power-house I see that he has allowed for five sets; it seems to me that to get the greatest economy out of such a generating plant there are too many units, and that it would have been better if it could have been so arranged as to have made units larger and never to have more than two running at one time. There are cases in which we have very large works being driven off one unit, and then you have only the one superintendence of the one unit to provide for. Of course you have the standby plant as well. On page 932 Mr. Williamson states that his experience of "high-speed vertical engines running under the severe conditions of continuous heavy loads has been perfectly satisfactory." I can thoroughly corroborate that, for up to certain horse-powers I have found exactly the same thing. But in the case of getting up into very large horse-powers, such as 1,000 horse-power, 1,500 horse-power and upwards, we then have found the greatest economy resulting from either triple expansion engines and generators running at slow speed, or the compound horizontal flywheel type engines and generators, with condensing arrange-

Mr. Selby Bigge.

ments and superheated steam up to a moderate number of degrees, to dry the steam thoroughly, with all accessories such as Green's economisers, water-cooling towers, and appliances of that kind. I next come to the question of cables, which is referred to on page 932, and I notice that a light insulation is used to avoid short circuits. That may be very useful. Of course you have to take every case on its own merits, but after a certain number of years the light insulation generally wears off, and then you have no insulation at all. I prefer as a rule to keep the conductors as far as possible bare. Coming to the motors, Mr. Williamson says, "It must be owned that most of the success of electric driving has been due to the great improvements which have recently been made in manufacturing motors." That undoubtedly is a very great point. The construction of motors in recent years has advanced enormously, and breakdowns are almost unknown now with well-constructed, carefully made, motors. "At the outset a strong effort was made to cut down the number of sizes of motors." That is another point which I think is very important also in works, that you should have as few numbers of sizes of motors as possible, so that one set of spares will do for the whole of them. On the question of gear, Mr. Williamson says, "Friction gear is inefficient and cannot be applied for large powers." I quite agree with that. Also he says, "Belting is of course applicable to nearly all cases, the slipping being a positive advantage where heavy shocks and reversals of machines take place." I can thoroughly corroborate that. On the question of variable-speed motors Mr. Williamson gives some very interesting particulars, and the case he tells us of a 5 horse-power motor with a range of from 300 to 900 revolutions for the return stroke, running at the high speed of the motor, is very interesting in the case of a lathe or planer. I notice that Mr. Williamson states that there are about 110 variable-speed motors in use at the Sheffield works, showing that they have found those to be a distinct advantage. The rest of the paper deals very largely with motor tests, and will be no doubt very valuable indeed as a reference. On page 954 Mr. Williamson gives us the specific case of the Wellman charger, which shows the very great economy that can be derived from the application of electric driving. He says, "Summing up the advantages, we have a reduction in the wage costs of melting of 50 per cent., with an increase in the output of 25 per cent." That is very strong evidence in favour of such machinery. On page 962 Mr. Williamson says, "It would be interesting to hear some experiences of engineers with circuit-breakers fitted in such power installations as those described in this paper." If I may be allowed to give my own personal experience in the matter, it is this, that we find that for small machines and small tools, such as punches, shears, and such like machinery, the circuit-breaker is in most cases a nuisance rather than a benefit, and we find it best in such a case to apply distributing switchboards fitted up with fuses to the different motors. We find that to be the most practical and sound practice. The next point which Mr. Williamson deals with (on the same page) is the saving due to electric driving. It is very difficult indeed to arrive at the saving due to electric driving unless you have absolutely parallel cases—that is,

unless you take a works that was formerly driven by steam and completely equip it with electric power, and then compare the results after the transformation with the actual work done before. That is the only way to get at an accurate result. Some time ago I spent a very great deal of time and attention on that very point, and I tried to get a number of statistics. I found that in the majority of instances the saving due to the introduction of electric driving in place of steam (that is to say, in works such as shipyards, or works where the power was subdivided up into a very large number of units) varied between 35 and 50 per cent. That was drawn not from one case, but from a great number of different works. I got the opinions of the different works' owners and managers on that very point, asking them what they had found was the actual saving after the substitution of electric driving for steam. It varied, as I say, between 35 and 50 per cent. I see that Mr. Williamson has done even better than that, because he states that at their works the actual result was the saving of half the coal bill, with an increase of over 50 per cent. in the output. Mr. Selby Bigge.

Dr. B. WIESENGRUND: It would be interesting to learn from Mr. Williamson whether, at least for the plants erected in 1897 and later, alternating current has not been considered; or what have been the reasons for adopting 220-volt continuous-current plants even for the latest installations. Considering the large extent of the works, it would seem likely that alternating current would have offered advantages in first cost as well as in maintenance. Perhaps the question of speed regulation gave the decision in favour of continuous current. It may be of some interest that the difficulty of speed regulation with alternating-current motors is overcome in an arrangement patented by Mr. Wüst, Zurich, who uses different stators and rotors with different numbers of poles combined in a common casing. The outputs of the different elements need not be necessarily equal; it is possible to arrange, for instance, the maximum output at the lowest speed. These motors, together with suitable gearing arrangements, give exceedingly simple designs of electric machine tools which I might differentiate from those originally designed for other kinds of drives. For the complete success of electric power transmission in engineering works it seems necessary that machine tool manufacturers and electrical engineers should work in unison, and probably this union would bring to the front designs similar in simplicity to those of which I would have pleasure in putting before you some drawings and photo prints. In these designs the motor is a component part of the machines, and its attachment to the working portion, avoiding intermediate gearing, produces a considerable saving in power and first cost of the machines, besides the latter being much more compact than the ordinary designs. The application of a continuous-current motor with speed regulation described by Mr. Williamson in a vertical planer or slotting machine, the motor reversing at each stroke of the machine, is certainly very interesting, but it can only be regarded as an example of the hard work that modern motors can stand. Whether such an arrangement is advisable from a technical point of view seems doubtful. The special conditions in planing machines, namely, slow working and quick Dr. Wiesengrund.

Dr. Wiesengrund. return stroke, make it desirable not to reverse the direction of rotation of the motor, but to make use of the kinetic energy accumulated during the working stroke in the motor or a flywheel for the quick return stroke, and only to raise the speed of the motor together with the reversal of the machine. An arrangement similar to that adopted in a hoisting drum, namely, two bevel wheels always engaging with the driving wheel on the motor shaft, the wheels being operated by a friction clutch, the coupling to the machine formed as a flywheel would answer the purposes. With a multi-speed Wüst motor it is very simple to change direction of motion of the gear and motor element in circuit by means of one lever automatically. In such a case a short-circuited rotor can be used, as the motor can be started in the central position of the clutch without load. It would be interesting to learn whether any experiments have been made in this country to regulate the speed of continuous-current motors by means of altering the depth of the air-gap. Mr. Wüst has designed, patented, and successfully applied this principle to many motors with two, four, and more poles, always operating with a single lever. With regard to the gearing, it would be interesting to hear whether any experiments have been made at Messrs. Vickers, Son & Maxim's with double helical wheels. The advantage of such wheels is the entire absence of backlash, ensuring noiseless running, especially if the wheels are machine-cut out of the solid, as patented and manufactured by Messrs. Wüst and Co., Seebach-Zürich. As double reduction gears, in a special arrangement made as a substitute for worm gears, for reductions up to 1:60 a minimum efficiency of 90 per cent. can be guaranteed.

Mr. Allen. Mr. W. H. ALLEN: In reference to the driving arrangements shown on page 935 of Mr. Williamson's paper, nothing is said with reference to the resistance which is given in the matter of shafting. When we designed the works at Bedford I thought that we might bring about economies in some directions by improvements in the mechanical movement, so I sent round to a large number of works in this country and in America to compare notes how they distributed the resistance from the generating power independent of the drive, that is whether it was mechanical or electric. We found that the average was something as follows: one-half of the power was expended in the shafting, the other half was expended in the movement of the tool and the work done. No tool maker has yet made any determination to try and improve the efficiency of the tools, and it is lamentable to see what a large amount of effort is taken in actually working the tool, while so very little is taken in the actual work done of cutting the metal. The best and largest tools only give us a duty of about 30 per cent. of the total generating power, while in the case of the smaller tools they give us as low as 10 or 15 per cent. Nothing much can be done, however, in the economy of these two divisions of the generating power; but in the matter of the shafting we have been enabled to show a very considerable saving by dispensing entirely with the top gearing. The power taken for driving the shaft may be divided as follows: it is 50 per cent. for the whole shaft, 25 per cent. being for the shafting pure and simple, while the top gearing absorbs the other 25 per cent. If the

latter can be dispensed with, we have a wholesale saving of 25 per cent. of the total generating power. At Bedford we made an effort to save that, with very considerable success, by eliminating top gearing and substituting a cone or sleeve on the shafting itself, which was worked by a cone clutch. It may surprise those who have never gone into it, to learn that of the whole number of tools at work in an engineer's shop, nearly half are idle all the day long; only 50 per cent. of the tools are actually at work at the various processes which they have to perform. When tools are idle, under the old mechanical form of drive, you have to work the top gearing and the belting at a loss of 25 per cent., whereas at Bedford, by the means we have employed there of using the cone, the moment the machine is out of gear the whole of its resistance is saved against the generator. I hold that to be a very considerable saving. It has been adopted by several other gentlemen who have built works since we started. There is one other advantage in the employment of this particular form—that is, that each tool can be driven separately by an individual motor in case of emergency, as for overtime or in the dinner-time. We have a small barrow in which there is a motor which is wheeled up to any particular tool, and in a few minutes that tool is at work independently of the main generating plant. As I have said, the saving derived from the method we have employed at Bedford is as much as 25 per cent. of the whole of the generating power from the main engine. I think that is worth knowing in designing works of this description. Mr. Allen.

Mr. J. S. FAIRFAX: Mr. Williamson, in his most excellent paper, says that 1,311 motors have been applied to driving eleven different classes of works in seven different districts or workshops throughout the country. It seems to me that the experience which he gives us will be of the utmost importance and advantage to both mechanical and electrical engineers. He states also his experience of the gearing that he has employed. He has used seven different kinds of drive, but the only three which he feels are to be depended upon are spur gearing, belting, and chain gearing. So far, the machine tool makers have designed their machines from the line shafting, and therefore when you apply electric motors to the driving of these tools there is a great difference in the speed, which must, of course, be reduced by outside gearing. Mr. Williamson seems to have endeavoured to standardise his speeds as well as the dimensions of his motors, for it appears that the majority of them (although, of course, there is a great deal of discrepancy according to the work) were run at about 600 revolutions per minute. The electric motor builders do not seem to have met that problem as much as they might have done. They might have used some mechanical means for reducing their speed to a speed somewhat approaching that of a line shaft, as the full motor speed is seldom required. Mr. Williamson has used his variable-speed motor, and found it a very great success. Certainly it is an advantage to use it for many reciprocating tools, and also for drills and boring machines, and tools of that sort. I think his motor is capable of very large development in the future. Incidentally it is readily used to measure the power given to each tool under different conditions of working, Mr. Fairfax

Mr. Fairfax. and may thus bring about a great saving of power, as suggested by Mr. Allen. I have been giving some little attention to this matter of motor driving, and I would apply the gearing directly on the motor—whether it is an engine or an electric motor makes no difference; and instead of doing it in the usual way by reducing the speed outside the motor, I would make the motor pulley—supposing it is driving a belt—go round a fewer number of revolutions than the armature shaft. The model that is here is part of the motor itself, and gives a reduction of about 17 or 18 per cent., but the principle is capable of going up to about 35 or 40 per cent. reduction, so that in a case where you are using motors that have an armature speed of 600 revolutions a minute, the arrangement shown by the model would give, say, 400 revolutions a minute at the pulley. Then, if you were to put in a second pulley, as there is in the model, you could get a variation of speed. By turning the little steel shaft round there, you will see that the model shows three different speeds. There is a variation of about 1½ per cent. between those two pulleys, but you can make the variation much greater than that. If you put on an outside bearing, you can have four pulleys, and suppose the armature shaft is running at 1,000 revolutions, you can reduce down one pulley to 800, the next to 750, the next to 700, and the fourth to 650. You will notice the peculiarity that, although all the pulleys are of the same diameter, they give four different speeds, so that you can drive on to a drum on a lathe, dispensing with cone pulleys, and change your speed while the machine is running, so that you have not to stop the machine at all. You can do that from each end of the armature shaft. If you want the greatest reduction possible, without variation, you simply put on one pulley and make your full reduction on that. There is another arrangement by which speed can be reduced from perhaps 5 or 10 to one. The great point is that it can be put on any motor and be self-contained without any outside bearing whatever, so that the motor can be hung up on a ceiling, or fastened immediately to the wall, ready to drive a machine.

Mr. Barker. Mr. J. H. BARKER: I would like to controvert Mr. Mavor's remarks about the locomotive. He says a locomotive on a main line is run with no standby. Although the locomotive is reputed to be so reliable as to need no duplicate, yet if it is worked out, we find that the run per engine is only about fifty miles a day; the rest of their time is spent in the repairing shop. As a manufacturer, I should be very sorry to trust to a single locomotive in my power-house.

Mr. Russell. Mr. S. A. RUSSELL: I have read this paper with very great pleasure on account of the great number of facts which it lays before us. The paper is indeed so full of facts that it lends itself very little to criticism. I think that, perhaps, the best way of taking part in the discussion will be to give a few notes of my own experience of motor-driving at the Silvertown factory of the India Rubber Company. The whole factory is not driven electrically, as we have many good economical engines driving through small amounts of shafting, and it was decided that it would not serve any useful purpose to replace those engines by electric drive. We had, however, plenty of engines a good deal older which were not very economical, being supplied through long ranges of steam

piping or transmitting their power through a great deal of shafting. Mr. Russell.
We commenced by replacing those, and also by fitting electric drive to all extensions and new work. In that way we have arrived at a total of over 150 motors aggregating about 3,500 H.P., and varying in size from 150 H.P. down to 1 H.P. The class of work done is very various and is of a very intermittent character, and many of the machines at one part of the operation take several times as much power as the average. Our 3,500 H.P. of motors does not call for more than a maximum of 1,200 k.w. from the generating station, and the average output taken over all the hours of running is only about 300 k.w. That is partly due to the reasons just named, and partly also because we have to run at night for a very small load. I am sorry to say we cannot show such good results in the cost of generation as those that Mr. Williamson gives in his paper for the Sheffield Works. At the present time our plant is not working condensing, but we hope that it will be so shortly; and that, coupled with the low load-factor, makes our costs more like those obtained at Erith and Barrow than those very excellent ones which were obtained at Sheffield. As to the class of work that we do with electric drive, we use it for tools such as lathes, planers, drillers, and wood-working machinery; for machines for making rubber and guttapercha where we get very varying and heavy loads, for cable-making machinery, and for a number of general purposes, such as driving stamping presses, pumps, air presses, lifts, cranes, pile drivers, capstans, and fans. With regard to the question of separate motors for each machine or group of machines, we have made a general rule that any machine requiring more than 5 H.P. should have a separate motor, but we depart from this in various cases. For instance, we have a line of similar machines driven from a line shaft, and there we find it better not to drive all by one motor, nor to put a motor to each machine, but to divide the big group up into two or more smaller groups each with its own motor, arranged so that practically any number of machines can be used according to the requirements without ever having any appreciable amount of idle shafting or machinery running. Also we have found it advisable with machines such as stamping presses, punches, and planers, where there is a considerable variation in the load during a cycle of the operation, to group two or three together on a motor if it can be done without loss through a great deal of idle machinery running, the object being to save having to put heavy flywheels on the motors to overcome the variation of the load. We have also a number of motors smaller than 5 H.P., but we have avoided those as much as possible. It is necessary sometimes, owing to the position of a machine in the shop, or owing to the nature of the work, to use smaller motors, but I think that the extra capital cost and the lower efficiency, and, in the case of very small motors, the extra cost of maintenance, all tend to make it uneconomical to use motors of much less than 5 H.P. We therefore avoid them when possible. With regard to gearing, Mr. Williamson has named spur-gearing, chain-gearing, and belting as the only three gears which have given satisfactory results. We use all three of those, but we also use a great deal of worm-gearing, not for small loads or intermittent work,

Mr. Russell. but for driving slow-running machinery which in some cases takes up to 150 H.P. per machine. The machines are used in the manufacture of rubber, and they have a very heavy and varying load. We have found that worm-gearing has given us very satisfactory results. It is impossible to make accurate measurements of efficiency with a load varying in that way, but in comparing machines driven through worm-gearing and machines driven through a train of spur-wheels, we cannot find any very appreciable difference in the amount of power taken by the motors. I do not think the loss is anything like so considerable as many people suppose, if the worm-gearing is well made. I might mention that we are not using ball thrusts, but a thrust block something like an ordinary marine block; but the collars on the shaft, instead of being part of the solid forging, are separate collars threaded on feathers with distance pieces in between. These have been made separately, because we can more easily harden them and get a much better surface, and that makes an enormous difference in the friction losses. The rings in the block are phosphor-bronze rings, and between the collars and the rings are two loose rings, one of phosphor-bronze and one of steel, to reduce the surface speed of the rubbing parts. We have had these thrust blocks and worm-gearing in use for over two years, and the wear on the worm and thrust is quite inappreciable. They take up much less room than a train of spur-wheels, and they run much more smoothly and silently under a varying load. The cost of the worm-gear at various places where we have compared alternative schemes seems to run about 15 per cent. higher than the cost of spur-gear. With regard to chain-gear, we have not had much experience, as we have only a few drives with it, but we find it most useful where two shafts cannot be put far enough apart for a belt drive, nor close enough for spur-gearing. We find the chain-gearing is from 25 to 50 per cent. dearer than spur-gearing, and I should be glad to hear from Mr. Williamson whether he finds that there is that difference in his experience. Another matter which is referred to in the paper is the type of motor and the improvements made in recent years. All our recent motors are of course multi-polar with slotted cores, but we have a large number of smooth-core motors, both bi-polar and multi-polar, which have been in work for a number of years. There is no doubt that the small wire-wound armature with the smooth core is very inferior to the former-wound slotted-core armature. With the smooth-core machines with drum-bar armatures we have got very excellent results, and we have had motors which stand very severe work. We have several of 75 H.P. with smooth cores, which have been running for five or six years driving rubber machinery, where the load frequently varies from absolutely light load (that is, merely driving the machine round) to 25 or 50 per cent. over full load as the rubber enters and leaves the rolls. I am pleased to say that during all this time we have not had a breakdown of an armature on one of these machines. I think that shows that the smooth-core machine is really capable of doing a great deal more than many people credit it with. I should put the change from copper to carbon brushes as almost a more important change in allowing us to deal with motor drives as we do now. About

circuit breakers, we have tried circuit breakers in the circuit of our motors, but have had to give them up and to revert to fuses, as we find that they are very uncertain. In the shops, of course, they are exposed to a certain amount of dust and a certain amount of damp, and we were continually finding that the circuit breakers stuck. Mr. Russell.

Mr. E. KILBURN SCOTT: One thing which should be borne in mind in applying electric motors to a shop which has already been driven by shafting is the flywheel capacity of the motor. In making a motor we always try to get the armature and moving parts as small as possible; but if you put a motor to drive machinery which has already been actuated by line shafting, having a large number of pullies and belts and so on, you have there a good deal of flywheel power, and therefore, in applying motors to such machinery, it is well to provide flywheels on the motor shafts or else in the gearing. It might pay to reconstruct the motor, and as I suggested some time ago, build the armatures very large indeed—in fact build the armature outside the field so as to get increased diameter and weight. Mr. Kilburn Scott.

In one of the largest railway works in this country I recently noticed an overhead travelling crane which is somewhat novel. The travelling and traversing motions were driven by means of electric motors in the usual way, but in this particular case the heavy lift was effected by a pump and hydraulic mechanism on the crab. The pump was driven by electric power, and a very nice exact lift was obtained by means of the hydraulic ram, which, I believe, would not have been possible if the electric motor had been coupled-up direct.

The authors of both these papers have dealt only with continuous-current motors, but I do feel that in this motor work we are coming to driving by three-phase. From a purely manufacturing point of view, one finds that in plants fitted with three-phase motors there is never any trouble about breakdowns or difficulty with the starting gear. But with the continuous-current motors you may have a breakdown if the "no load" or "overload" release gets out of order, or, as sometimes happens, they are tied up to prevent them acting. It is the nature of the continuous-current motor to be coddled in this way, and, moreover, even if there is no sparking an attendant must go round regularly to fit new brushes. With a three-phase motor, having a short-circuited rotor, such as are used for driving a good many modern workshops, there are no brushes, and the starting switch is of the simplest kind with nothing to get out of order or be tied up. Again, more often than not motors get into dusty places, and a cover must be provided to protect the commutator, or the motor may have to be entirely enclosed and its output considerably reduced. Now I believe the enclosed motor is distinctly a fad, and it is very seldom, if ever, necessary with the much simpler three-phase motor.

Another point in connection with three-phase is that the motor speed depends primarily on the periodicity. And as most machines require a steady speed, the three-phase motor is thus very desirable. This feature is particularly useful when driving textile machinery, as is proved by the extensive adoption of the three-phase motor in textile factories abroad. It is often urged against the three-phase motor that

Mr. Kilburn Scott.

you cannot get a variable speed with it, but such variation is easily attainable. For small variations resistances can be used, and for large variations the cascade system or varying the number of stator-poles may be employed. As a matter of fact the long taper cone pulleys with a short belt between gives a very easy and cheap method of varying speed for large lathes, etc. I do not think, therefore, that you can bring the objection against the three-phase motor that you cannot get variable speeds, because if need be you can get large changes by altering the stator-poles, and you can get small intermediate changes by a pair of taper cone pulleys. Another point is that if you go to the trouble of measuring up the space occupied by a three-phase motor as compared with a continuous-current motor, you will find that if you are limited to space, you will get your three-phase motor in all right where you will not get the continuous-current motor; that follows from the construction of the two machines. Whatever may be case just now, the three-phase motor is bound to come out cheaper in the end, as it is so much easier and cheaper to make.

It may be mentioned that there is very much greater uniformity in the speeds of three-phase motors: thus at 50 periods per second no synchronous speed is possible between 600 and 750 or between 750 and 1,000, and whatever the make of motor the speed will be these figures less the slip of 3 or 5 per cent. as the case may be. Without effort or trouble therefore the speeds of three-phase motors have become standardised, and this is a very real convenience when applying such motors to machines.

Mr. Gaster.

Mr. L. Gaster: I can also corroborate the great advantages of applying electric driving in works. Allusion has been made to the use of the polyphase motor for driving in factories, and whilst not wishing to discuss at this juncture the merits of the polyphase *versus* direct current, I should like to mention a case which came under my notice during my visit to Roumania last year. I had the opportunity of seeing there the application on a very large scale of the polyphase motor used for boring the wells in the petroleum oil fields, for pumping the oil, and for driving all the tools in the workshop of the Company. The power is generated from a waterfall available about 25 miles away from the oil fields, and the fact that the water-power is cheaply transmitted and that the motors are sparkless when using the polyphase current, led the Company to adopt the polyphase in preference to the direct-current system. The Company is effecting great economies in using electric motors instead of the great number of scattered boilers and engines employed previously, which not only were more costly to run, but also more dangerous on account of the fire risks. The application of electric motors to the boring of wells is extending rapidly also in the Russian oil fields. I am often asked how it is that polyphase motors are not so much used here; but the reply seems to me to be simple enough, in that there has been but little opportunity here for their development up to a short time ago. There are, however, signs of an increasing demand in the near future, the reason being, that the power will have to be transmitted at a long distance from large central stations which are being established throughout the country. I

remember Professor Weber of Zürich teaching us thoroughly first as to alternating current, saying, that if you understand thoroughly the alternating current, which is the originator of the direct current, it is not so difficult to understand the latter. The progress made in the development of the polyphase motor gives every encouragement as to its future in this country. Mr. Gaster.

I should like to ask Mr. Williamson a question with regard to the generating plant used on the works mentioned. I notice that there is a very great difference in the cost per unit generated. At Erith, for instance, fuel costs 20s. per ton, and the works-costs there per unit are about 1·1d.; in Barrow, with a cost for fuel of 17s. per ton, the works-costs per unit are about 1·3d., while at the Electric and Ordnance Accessories Company, although the fuel costs 19s. 10d. per ton, they only pay 0·55d. for the biggest part of the works-costs per unit. Probably in the latter case it is due to the use of a gas plant (Dowson), which I notice that they have there. I see also that the present plant capacity is only 375 kilowatts, and that the annual output is only 364,000 units. Comparing the result of works (*g*) with those others where the price of fuel is the same, but where the plant capacity is larger, and the output ranging from 644,000 units to three and a half million units annually, the price at the Electrical Ordnance Accessories Company compares very favourably. I should like to know whether it would not pay in the future to have gas-generators for driving instead of steam engines? because gas engines can be made now for very large units, and they certainly have a great future before them. There is an enormous difference in the price of fuel between the two plants (*b*) and (*g*), and where fuel is dear, the economy produced in using gas engines is very great, the fuel item playing a very considerable part in the generating costs. Referring to the remark made by the author concerning the preference of fuses *versus* "overload release," I quite agree with him that the use of the fuse as a protection is a much less troublesome arrangement, but unfortunately there does not exist a sufficiently clear understanding between the different makers of fuse and fuse-boxes to produce one good type which could be adopted universally. I think that it is now time that something should be done in the matter, and that we arrive at some understanding as to the standard type to be adopted, and so do away with the existing discrepancies.

I wish to draw special attention to the following point. Some contractors say that they will make electricity very cheaply, and they put in the plant anyhow and say, "That it will be all right"; but they often omit to explain to the purchaser the proper way to treat his motor, leaving him under the impression that the motor can do wonders, but he soon finds out that in not having been provided with sufficient spare plant in case of a breakdown, the whole works have to be stopped until the repairs are done, which causes a very great loss. In factories where the value of the goods turned out by the use of the motor is of many times greater value than the cost of driving the motors, a breakdown leads to very great loss to the user of the motor. It must be pointed out that only the best class of workmanship and the best material have to be applied, if electric driving is to be used

Mr. Gaster. successfully and economically in the long run. There are several small trades like tailoring, cap-making, tobacco-cutting, etc., where electric driving could be considerably used, but the people are simply frightened away from motors on account of the troubles they sometimes give, which to my mind are mostly due to cheap and unreliable fitting up. Contractors ought not to undertake to put up motors, or any other electrical installation, at so cheap a rate as not to allow them to ensure good finish. They should remember that it will greatly assist the further development of the application of electric driving in factories, if they will explain to the would-be customer that it is absolutely necessary to have first-rate motors, sufficient spare plant, and that a judicious distribution of the driving power will make his factory more efficient. Only in this way can we safely expect a wider extension of electric driving generally.

Mr. Patchell. Mr. W. H. PATCHELL: In regard to the remarks of previous speakers in the discussion, Mr. Barker has said that locomotives only run one hour a day, and spend the other 23 in the repairing shop. I do not understand the figures! [Mr. Barker: I said they only ran 50 miles a day.] You can take it as one hour, because they often go 60 miles in the hour. I think that we might probably prove by figures that the whole of the electric plant in the country could do the present output if worked one hour a day at full load, such is the inefficiency of the conditions under which it is worked. Then Mr. Scott votes exclusively for three-phase motors. I do not think really that there is a "best" for everything. Each has its best place. I have between 9,000 and 10,000 horse-power in direct current, and I have between 9,000 and 10,000 horse-power in three-phase current; but I do not throw down my challenge and say which is the best—each has its best place. We hear a great deal glibly talked about the variable speeds of three-phase machinery; but when you ask a man who is talking like that to put his views on paper and talk about an order, he is immediately very busy—he has to go off somewhere else very urgently, and he cannot attend to it!

To come more directly to the paper, there is one important point in factory driving which I should like to know more about, if Mr. Williamson would tell us. As regards generators, they are generally wound as shunt machines. In the paper sometimes Mr. Williamson says "shunt" and in other cases he does not say whether they are shunt or "compound." Station men, in thinking of a dynamo, generally think of it as a shunt machine, because if we are fortunate enough to be supplying direct current, we want to put them in parallel with the battery, and if you start doing that with a compound machine you often get fireworks; so we generally go in for shunt machines. [Mr. Williamson: They are all shunt right through.] A small compound machine will do for small works better perhaps than a shunt; but when you get into big works, I think that a shunt machine is the best thing to put in. Has Mr. Williamson tried the compounding of motors? [Mr. Williamson: Many of them are compound.] I think that one of the prettiest things described in the whole paper is the variable-speed reversing motor. One has been in the habit of using heavy planing

Mr. Patchell.

machines, taking a cut in each direction, but if they are vertical machines there are difficulties in the way of doing that, and this is a very beautiful instance of the way in which the electrical engineer can come to the rescue of the manufacturer. Mr. Allen mentioned his cones, but I do not think that he said enough in favour of them. I was greatly struck by the use of them on small tools when I went through the Bedford shops some six or seven years ago. They are not only very handy, but they save in the construction of the shop, and they also save light. You get the light down far better if you have got no horizontal belts from the main shaft across to the counter shaft. Mr. Russell spoke about smooth cores and slotted cores. I have tried both. I have had smooth cores with steel teeth; in the course of time they chafed through—the machines I am speaking of now are probably ten or twelve years old, and the machines of that date got rather warmer than machines do nowadays; that helped the cutting through, because the expansion during load slackened up the insulation, and then when we ran up again we got more chafing. As time went on we got machines with wooden teeth; they did not short-circuit on the steel pegs, because there were no steel pegs to short-circuit on; but if you happened to have a short-circuit outside, you could take the teeth out by the handful!

Mr. Hammond.

Mr. R. HAMMOND: It is a very great pleasure to have results placed before us in so exact a manner as they are in Mr. Williamson's paper. It is a tempting paper, but I will just confine myself to discussing the point of cost of production. Some years ago, on one of the earliest Power Bills, Mr. Williamson was produced as one who could show that electricity could be generated and distributed at under one penny per unit, which in the dark ages of 1893 was considered a very low price indeed. Here he shows that in the two Sheffield works he has brought the costs down, in the one case, to 0·716d., and, in the other case, to 0·675d. He certainly does demonstrate a fact that is often questioned, namely, that it is quite possible to produce and distribute electricity at a profit at a penny per unit. With the average costs that appear in the Journal that was referred to by Mr. Mavor of 1·5 and even 2d. per unit, Parliamentary Committees wonder how it is that any portion of the power can be produced at so low a figure as 1d. per unit; but here we have it in black and white, and that most satisfactorily disposes of the idea that it is an impossibility. I should like Mr. Williamson in his reply to tell us how it is that his coal comes out at so high a figure. With such a magnificent load-factor I should have thought that the coal would be less, in the case of the North Sheffield station, than 0·315d. per unit, and in the case of the South Sheffield station, than 0·255d. per unit. We are well acquainted with stations in this country which, working on the very moderate load-factors of 10, 11, and 12 per cent., are achieving results equal to that; and I am curious to know, as I am sure we all must be, how it is that, at Sheffield, so high a proportion is absorbed for coal. Possibly Mr. Williamson in his reply will be able to give us an idea of the calorific value of the Sheffield coal. The very high cost of coal seems to me to be the only weak spot in the paper.

Mr. Patchell.

Mr. W. H. PATCHELL: Mr. Hammond got very near it, but he did not quite hit the bull's-eye this time. The figure for coal in the paper is per unit generated, and the coal that Mr. Hammond has in his mind (which he has got from the *Electrical Times* tables) is coal per unit sold —which is a very different thing.

Mr. Hammond.

Mr. HAMMOND: Thank you; I am very much obliged to you for pointing that out.

Dr. Rhodes.

Dr. W. G. RHODES (*communicated*): One of the points naturally arising out of Mr. Chatwood's interesting paper is the choice between alternating- and direct-current motors for machine driving.

As the author points out, where the speed of the machinery is required to be constantly varied between wide limits the advantage lies with the direct-current motor, but if, as is often the case, the speed should be kept as constant as possible, the alternating-current motor has decided advantages. In private installations the current taken by the motor at start is not a matter of great importance, and an induction motor of the squirrel-cage type can now be made to rival the shunt-wound direct-current motor both as regards efficiency and constancy of speed, and at the same time is quite free from sparking troubles, which constitute the great drawback of direct-current machines. Not only is the fire risk less with induction motors, but they require less attention and cost but little in repairs.

I must say that I differ from the author in advocating the purchase of power from Corporations. It is quite true that the large margin of power available is an argument in favour of this; but where the demand is large it is far cheaper to install a generating plant, on account of the lower standing charges and the fact that there is then no network of mains which have to be paid for out of revenue. It not unfrequently happens, too, that a Corporation refuses to connect motors above a given rated power, on account of their inability at certain times of coping with such a large additional demand.

The lowest charge made, to my knowledge, by any Corporation for energy is 1d. per B.O.T. unit, and this charge is only reached after a certain minimum demand is guaranteed. If, as is frequently the case, there is available steam, a private installation can generate at a cost of ½d. per unit; in fact it can be done at this price including all charges for interest, depreciation, etc., by installing a gas engine with direct-driven generator.

The precaution of arranging that the voltage of the private installation should be the same as that of the town supply is a very wise one, for then the latter can be counted on in an emergency.

Mr. Aitken.

Mr. JAMES AITKEN (*communicated*): With regard to Mr. Williamson's choice of a voltage under 250, I agree with him that it will meet the requirements of all ordinary-sized works. If this pressure is exceeded, certain restrictions are imposed by the Board of Trade, and special care has to be taken in the selection of suitable controllers for voltages of 400 and upwards to prevent sparking. In the works I am connected with—the class of machines are ship-yard tools—we have adopted the individual motor drive for the machines, and, wherever possible, have used direct spur-gear drive from the motor to the

Mr. Aitken.

machine, the gear consisting of forged steel pinions and steel-rimmed wheels machine-cut. In using spur-gear care should be used in selecting the motor, as the ordinary motor for belt drive is generally too light in the armature spindle, and causes chattering. Until recently it was difficult to get motors suitable for spur-gear; these can now be obtained, and there is no reason why spur-gear should not be more generally used, and thus do away with the belting and attendant pulleys.

On page 1004 is a list of a number of machines showing the current taken, horse-power to drive the machine, and horse-power doing useful work. It may be interesting to compare these with the list in Mr. Williamson's paper. The tests have been taken from the machines working under normal conditions.

It will be noticed that in many cases the power consumed in driving the machine empty is a very great proportion of the total power used. This is also shown in Mr. Williamson's results. The object one should keep in view is therefore to get your motor as close up to the work as possible.

As an example of this, take a high-speed radial drill running at 400 revolutions per minute with $\frac{3}{4}''$ twist drill.

Horse-power registered to drive machine	7·5
Horse-power registered to drive machine running light ...	5·0
Horse-power doing useful work	2·5

This machine is direct spur-geared in the usual way. If a variable-speed motor be placed on the drill-spindle saddle, and direct connected to the drill spindle with a pair of bevel wheels, 4 H.P. would be saved. In the latest practice this method is being adopted.

With regard to the fluctuation of the load, the cranes give the most trouble, as they take a large amount of current for short periods. If the

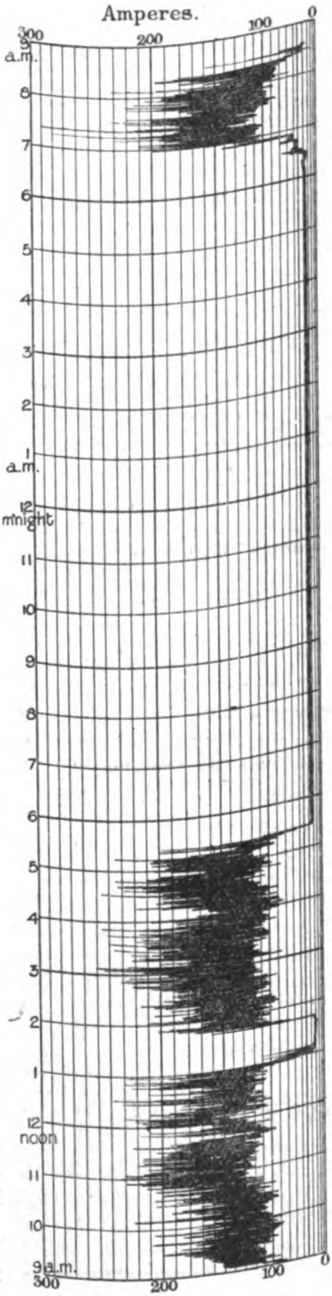


FIG. A.

List of Machines, with Horse-Power Required, etc. 220 Volts. (Aitken.)

Type of Machine and Work Operated upon.	Amperes Required by Machine.	H.P. to Drive Machine.	H.P. used for Useful Work.	Remarks.
Cold Iron Circular Saw, cutting 14″ × 6″ R.S.J	12½	3·68	2·2	Drive, direct spur-connected, steel wheels.
Ditto, running light...	5	1·48	...	
Iron Band Sawing Machine, cutting solid steel Bloom 3″ thick ...	7	2·06	·58	Drive, direct spur-connected, steel wheels.
Ditto, running light...	5	1·48	...	
Joist Straightening Press, straightening 5″ × 4″ × ⅝″ steel angle ...	15	4·42	1·36	Drive, direct spur-connected, steel wheels.
Ditto, straightening 16″ × 6″ R.S.J.	70	20·6	18·54	
Ditto, running light...	7	2·06	...	
Large Double-punching Machine, punching 1″ holes through ¾″ plate	20	5·9	·6	Belt drive, very heavy flywheel.
Ditto, running light...	18	5·30	...	
Punching and Shearing Machine, shearing ⅝″ plate, punching ¾″ in ¾″ plate	35 average	10·3	7·38	Drive, direct spur-connected, steel wheels.
Ditto, running light...	10	2·93	...	
Combined Punch Shears and Angle Cutter, cropping 6″ × 4″ × ⅝″ steel angles...	45	13·3	9·9	Drive, direct spur-connected, steel wheels.
Ditto, running light...	12	3·40	...	
Battery of 4 Radial Drills, broaching out ⅝″ holes to ¾″...	15	4·42	2·94	Drive, direct spur-geared to underground shaft. Machines bevel geared to shaft.
Ditto, running light...	5	1·48	...	
Stancheon Facing Lathe, facing stancheon one tool ¼″ cut × 1/16″ feed	10	2.93	·87	Drive, direct spur-geared to headstock.
Ditto, running light...	7	2·06	...	
Horizontal Drilling Machine, drilling ¾″ hole, 160 revs., twist drill ...	10	2·93	1·45	Belt drive.
Ditto, running light...	5	1·48	...	
Joist Milling Machine, milling 10″ × 5″ R.S.J.	12½	3·68	2·2	Drive, direct spur-geared to machine.
Ditto, running light...	5	1·48	...	

In the above list the amount of power consumed by the machine is shown, also the actual power consumed in doing useful work.

Mr. Aitken.

crane-load is very considerable, in comparison with the machine and lighting loads, it is advisable to run the lights off a separate generating set. Fig. A. shows a tracing from recording ammeter card for 24 hours. The sudden fluctuations are caused by the stopping and starting of the electric travelling cranes, which are of the three-motor type and for six-ton loads.

With regard to polyphase working, the variations in speed and torque in an engineering shop are so great that one is compelled to decide in favour of the continuous current, in spite of the inconveniences of the commutators, until such time as the polyphase motors can be made to do what continuous-current motors will do.

Mr. Andrew Stewart.

Mr. ANDREW STEWART (*communicated*): The comprehensive nature of up-to-date electrical engineering makes it difficult to give the specialist in one particular branch of the industry a very frequent innings; considering the importance of electric motive power, the papers which have just been read on the subject will put on record much that is valuable. Mr. Chatwood's preference for direct currents must, I fear, be due more to a lack of acquaintance with multiphase currents, than to any disadvantages which are inherent in them; certainly the cases which he cites, are those in which constant *not* variable speed is required. Under these circumstances, surely the author will not argue that direct currents have any advantages over alternating; indeed the latter are just the proper thing in the cases under consideration. That the author should condemn the adoption of four motors in preference to one, because on paper a balance of 2¾ per cent. per annum can be shown in favour of the latter is, one might think, a little dogmatic. There might easily be collateral advantages which cannot often be accurately expressed in £ s. d. that would overbalance the small difference; if part of the works made even a very small amount of overtime, judicious grouping to several motors would easily turn the balance in favour of more than one motor.

The glimpses which we get of the efficiency of some modern direct-current motors, is a striking commentary on the result of unlimited competition; the motors may be mechanically strong, but what engineer who has been engaged in testing them can say that equal progress has been made in efficiency? Of course the idiosyncrasies of the purchaser have had something to do with this; people seem to want a motor which is as invulnerable as a modern ironclad, and with as little hum as an empty beehive, yet as cheap as possible; something must be sacrificed, and efficiency is frequently offered as a sacrifice to the other and more desirable (?) features.

Mr. Williamson gives us a paper which from a practical point of view could scarcely be beaten. To the man who installs large power plants many of his deductions are not new, while others permit of different views. Not every one has been so fortunate with chain-drives as the author seems to be, but the performance of these are chiefly governed by environment; there are many cases where they may be employed in place of worm or double-reduction spur-gearing, though where the ratio of reduction and space permits, single-reduction spur-gear would be hard to beat. There are, however, cases when it seems

Mr. Andrew Stewart.

reducing gear is scarcely justified at all. Take cases where moderate speeds of 500 to 650 revolutions per minute are required, and horse-powers of 5 to 10 or 15. In how many cases can one find high-speed motors with spur-gear used, even where considerations of space are not paramount? Taking motors of the aforementioned horse-powers and comparing slow-speed motors of 600 revs. against high-speed motors of about 1,300 revs. with spur-gear, the efficiency is in all cases about 6 per cent. in favour of the slow-speed motor, while the capital cost is only 10 per cent. in favour of the geared motor. Considering that a 15-H.P. motor using energy at 1d. per unit can in a year take electrical energy to the value of twice its capital cost, the small extra interest charge involved in the slow-speed motor is saved from 8 to 10 times over in a single year; yet how many examples of geared motors can be found, with nothing except lower capital cost to justify their existence.

The variable-speed motors which the author mentions on page 937 are not by any means new, but the limit has hitherto been set at much less than 100 per cent. increase, due chiefly to sparking difficulties. Perhaps he can tell us if commutation takes place under a pole horn maintained at constant strength by some means; it does not appear likely that satisfactory commutation can be obtained without some special commutating device. The switch Mr. Williamson mentions does not seem to present any difficulty, and has been used for this purpose before; the patentable features should certainly prove interesting to the men who have for years been engaged on problems connected with speed regulation.

The crane speeds which the author gives are of more than academic interest; nothing is more conducive to economy in engineering and shipbuilding yards than the rapid handling of heavy weights. Who in charge of a shop has not seen expensive machines, almost equally expensive skilled workmen, and a small army of labourers idle, while a steam or rope-driven crane crawled down the shop with the work? Such a spectacle never fails to raise the back of an employer, and by directing attention to this aspect of the question, one is more likely to succeed in convincing works owners of the advantages of electricity than by means of the mathematics which Mr. Chatwood has inserted in the closing pages of his paper.

The question of a spare plant in a works generating station is raised by Mr. Williamson, and it is remarkable how central-station practice has stamped itself on many installations. It may be questioned whether, in many works, the outlay of 20 per cent. of the capital on spare plant can be justified. The works owner must first of all be convinced that electricity is quite as reliable as his old plant, and if he is told that a certain proportion of his generating plant has to be in duplicate he will not feel reassured. He argues, not unreasonably, that he does not at present duplicate his boilers and engines, and cannot see, if electric power is quite as reliable, why he should put in spare generating plant. Many works get along quite well on no spare plant; I have been connected with several works plants from 200 to 1,000 H.P. where no spare plant has been installed, and in two cases six years' running has not yet shown that any risk was involved in

dispensing with the spare plant, even where in one case a night and day shift is the rule: such repairs as have been necessary in the generating station have been executed during week ends and holidays, just the ordinary factory routine. Mr. Andrew Stewart.

The table of costs per unit emphasises what has been recognised by engineers engaged in power work, viz., that no plant over 200 H.P. can afford to buy its energy; wholesale power generation is cheap, but it costs too much to deliver it at the factory. Capital charges on mains and sub-station plant unduly burden the large undertaking, while the losses in transmission and transformation have also to be reckoned with.

A works of any size can purchase coal almost as cheap as the large generating station; it can put down its generating plant at almost the same cost per kilowatt, and if it does not generate as cheaply, the difference is only a very small fraction of a penny per unit.

Mr. H. O. WRAITH (*communicated*): Mr. Chatwood gives tables stating the maximum brake-horse-power required for certain tools, but these figures do not really give any useful information, for so much depends on the feed and speed, that is to say on the amount of metal removed in a given time. Only within the last week I was in communication with a firm (not electrical engineers) who had been inquiring for large lathes, driven by separate motors, and the sizes of motors quoted for by various toolmakers varied from 4 H.P. to 120 H.P., for what was nominally the same lathe. The reason for the discrepancy was that the firms quoting low-powered lathes were offering machines which would only remove perhaps one-tenth of the metal in a given time that the higher-powered lathes would. The firm offering 120 H.P. made no mistake about being able to do the work required. Mr. Wraith.

It would be interesting to hear if the author of the paper has taken any tests on the basis of measuring the actual work done by the machine-tool. I think the figures the author gives as to grindstones used for dressing, etc., are, for this class of work, rather low, and I should be sorry to put two great hulking seven-foot grindstones used for these purposes on one poor little 15-H.P. motor in a shop where any attention is paid to getting work out quickly, and therefore cheaply. It is the usual thing for the grinder, when dealing with long bars, to sit on the bars when grinding, so as to get more weight on, and I have often seen a single grindstone take 13,200 watts, or roughly 15 H.P., when grinding bars, say, two and a half inches wide.

The method of starting grindstones and similar machinery with heavy moving parts by means of a magnetic clutch is very ingenious, but has Mr. Chatwood any experience as to the wearing qualities of such a clutch? for my experience of clutches is that the cost of renewals, adjustment, and repairs more than overbalances their advantages. It appears to me that a simpler and better method is to have a shunt motor with a few series-turns on, a starter of some form that is not likely to take any harm from being overloaded now and again, for preference perhaps a liquid starter, and see that the man who starts the motor knows what he is doing, and starts slowly. The arrangement the author proposes is very susceptible to injury in incompetent hands, more so than the simpler arrangement above, where about the worst a man

Mr. Wraith. can do is to blow the fuse, and, unfortunately, in the majority of places it is very difficult to keep electrical machinery out of incompetent hands.

Mr. Chatwood recommends the use of storage batteries in private stations of considerable size. Has he any figures in support of this? The difference between the ordinary day-load and, say, overtime load may be great, but in an installation of any size the percentage of variation of load during ordinary working hours is very little, and if the installation has been properly designed, the generating plants are of such a size as to fit in with the different loads at different periods of the twenty-four hours, so that whatever generating plant is running, is running as near as possible to its maximum and therefore most efficient load. The battery is only occasionally useful and economical, on small overtime loads, and taking into account its heavy first cost, space it occupies, and large depreciation, I think there is no doubt, in nearly every case, it is not worth putting in, and that it is cheaper in the long run to keep an engine running for overtime, except perhaps in the case of offices, which hardly come under the head of machine shops, or where there is a lot of Sunday repair work done, which would necessitate, in the absence of a battery, firing up a boiler. Such places where Sunday work is done are, however, few and far between, and in such cases a better solution of the local problems would probably be found in a gas-driven plant.

Mr. Chatwood. Mr. A. B. CHATWOOD (*in reply*): Before I reply to one or two points made by speakers in the discussion, I should like to congratulate Mr. Williamson, first on having had the opportunity of dealing with works such as those described in his paper, and secondly on having had the unselfishness to give us experimental results such as he has done in his paper, of which I do not think we can fully appreciate the value here and now. It is in the months to come that we shall find out how valuable they are, when we use them constantly for reference. On pages 934 to 936 of Mr. Williamson's paper he speaks of the driving cost differences with various groupings of a certain number of lathes, and he says the working conditions would be fairly represented by assuming eight out of ten machines to be in use, the remaining two having tools or work changed or set. Unfortunately my experience has not lain in shops where that statement would be at all true. The probable working conditions in these shops are that about two tools out of ten would be working, and the advantage, therefore, in those cases of a divided drive would be very much more pointed than is shown by Mr. Williamson. Mr. Allen has explained to us a method of driving which, personally, I had not come across to any extent, but I think that in the bulk of small shops the 25 per cent. which he put down as a saving would be a long way off the mark, because the abolition of counter-shaft arrangements and belts off the line shaft would, I think, cause a saving of very much more than that—at any rate, in shops such as I have been speaking about. Mr. Scott called attention to a matter that is mentioned I think, in both the papers that were read—that is, to the use of a flywheel or a very large armature. I do not think that its importance can be very much exaggerated in some cases with reversing machines and with machines with intermittent load. He also

Mr. Chatwood.

spoke at some length on three-phase plant, and Mr. Patchell made some remarks about it. I have been for the last two or three months carrying out experiments in a cotton mill in order to determine a good many points that never have been determined as far as one can find out, about driving cotton machinery electrically, and I think I may say that in all probability the mill is going to be driven electrically. It is a small Bolton mill of 125 H.P., and one of the great objects of going in for the conversion to electric driving is the doing away with all the bother of having driving plant of any sort to look after. The Corporation of Bolton can supply either single-phase alternating current or direct current. This mill, I need not say, will be driven by direct current. At the same time, I have no doubt whatever that if electric driving spreads into the cotton mills of Lancashire, three-phase plant will be put down, and I think very likely some go-ahead towns—such as, perhaps, Bolton—will go in for supplying three-phase current specially for mills at a price considerably under a penny. But I do not think that three-phase motors are universally applicable for driving machine tools. One of the very great advantages of electric driving is the question of delicate speed control, and of not being compelled to jump from 200 to 400 revolutions, or from 400 to 800 revolutions, or anything of that sort. Personally, my experience with polyphase motors is that up to the present they are certainly deficient in speed variation. Mr. Scott advocated the use of long cones and belts to get over the difficulty of delicate speed control with the polyphase motor, and he said that belts were good enough for our grandfathers and they were good enough for our fathers, and I understood him to infer that therefore they are good enough for us. I think the object of having papers at this Institution is to advance a little on what our grandfathers did. I do not want to say very much about our grandfathers and fathers ; they were very good people in their way—at least mine were—but I have spent some eleven years in connection with works where that principle was carried out, and I must say that, as far as one's work was concerned, I never had such a miserable time. Mr. Scott also spoke about armatures burning out. I have had experience of a good many motors, and I have had, in machine-tool driving, one case of an armature being burnt out. I was not very much surprised about it, because it was a motor that I built myself for experimental purposes about fourteen years ago.

Dr. Rhodes has somewhat mistaken the view I attempted to express at the end of my paper on the question of generating current. I most cordially agree with him in saying that where the demand is large it is better to generate one's own current. The point which I wanted to enforce in my paper was simply, that if you can purchase current from an outside source as cheaply *or nearly so* as you can produce it yourself, then it is better to save the worry of having another department to look after and devote the portion of your energies thus saved to increasing your own particular business. I do not think that in any of the particular cases given in my paper, especially as none of these shops have any electrical people at present, Dr. Rhodes would advise generation on the premises.

Mr. Chatwood.

I can quite believe Mr. Wraith's statement as to the various powers quoted by tool makers for the same lathe, as I have experienced a case in which the tool maker who built a machine stated that a 6 H.P. motor was big enough for it; a 40 H.P. was put upon it, and this has been replaced by a 60 H.P. Quite apart from this ignorance of some tool makers, the cutting power of what is nominally the same lathe by different makers varies enormously.

Tests of the nature suggested by Mr. Wraith hardly come within the scope and object of the paper, which was intended rather to point out what is actually taking place in connection with electric driving installations of small shops carried out by men absolutely ignorant of the subject, and to point out some, at any rate, of the numerous factors which should influence the arrangements of any particular case. I can, however, give the figures obtained on a 6-inch lathe during the course of some experiments which I carried out on various samples of steel: but I should not like any one to expect a result anywhere near this in ordinary practice, as the circumstances were here entirely special.

The steel cut was 1 in. diameter bright drawn bar, cutting speed 50 feet per minute, tool $\frac{3}{8}$ths round silver steel very carefully treated, held in a Smith and Coventry holder, cutting angle 55° 15'; front clearance 7° 55'. Rate of cutting, 22·84 lbs. per hour. Power absorbed at tool point, 0·314 H.P.—equivalent to 72·6 lbs. of steel removed per hour per H.P.

The grindstones referred to in the paper are not used with the object of removing as much metal as possible, but simply for removing rust and scale and for dressing small rivet heads: the powers given in the paper have been obtained from actual practice. Where, however, stones such as these are used for heavy work, as is the case in the manufacture of textile machinery, the power absorbed will sometimes surpass the figures given by Mr. Wraith.

Mr. Wraith is, I think, under a misapprehension as to the magnetic clutch. The arrangement described, somewhat imperfectly perhaps, is not a mechanical clutch magnetically operated, but entirely magnetic, the two parts of the clutch being separated by a fixed small air-gap, so that there is in the clutch itself no wear.

I must flatly contradict Mr. Wraith's statement that I "recommend the use of storage batteries in private stations of considerable size." In small shops such as those described in the paper the fluctuations of load are considerable—from 2·5 to 9·3 H.P. in one case, from 4·6 to 23·6 H.P. in another. The statement in the paper is, I think, rather a reminder that it is desirable in each particular case to consider whether or not batteries would be advantageous. So many local circumstances enter into the matter, that it would be impossible to form any general opinion.

Mr. Andrew Stewart seems to have read the paper somewhat carelessly, as in the three cases cited specificially, pages 979 and 980, as well as in the summary of the possible advantages of the installation of electric driving, page 971, the advantage of variable speed is sufficiently insisted on. I expressly stated, however, that in my opinion there was no general question of alternating and continuous current, but that every case must be decided on its merits.

I should like to point out that I did not condemn four motors instead

of one in Case 2 because of the slightly increased cost, but because "almost the whole of the shafting is to be driven and no one of the advantages of electric driving is to be secured," and at the same time pointed out that the cost would be slightly higher. Mr. Chatwood.

May I refer to the diagram given in the paper with regard to two planing machines, as I think an analysis of them will give a clear idea of what goes on in shops such as those discussed in my paper. The power absorbed by the smaller machine when not actually cutting is considerably greater than that absorbed by the larger, although the speeds are slower, showing that the condition of the smaller machine is such as to require examination. It is hard for men trained in up-to-date shops to realise the conditions which prevail in shops which were all right thirty years ago, but which have not advanced in any way since.

I should like to feel that we, both as individuals and as an institution, are doing all we can to influence manufacturers and their managers to consider carefully every case of electric driving, and not to follow the policy which has been followed in the shops noticed in my paper, a policy which can only be described as "the shove-a-motor-down policy."

Mr. A. D. Williamson (*in reply*): I thank you very much indeed for the very kind remarks that have been made about my paper; I think almost too much has been said in that direction. If the paper is of value, it is simply due to the fact that I have been in the position to accumulate useful information. Now with regard to the discussion, the first point raised was the question of breakdowns. I have thought about it, but I cannot remember any serious breakdowns whatever. We have had to stop occasionally—possibly for a hot rod, or something of that sort—but dividing the plant in the way I have mentioned in the paper, we have always had some spare plant to carry on, and it has caused no stoppage of the works. If we had any trouble at all, it has been not with the electrical plant, but with the steam plant—with the boilers. I do not think the comparison between the large marine engines and electric generating plant is quite fair, because a steamer has to have one large engine—there is no help for it. If that breaks down, the ship is stopped. That large engine is always working at maximum load, and therefore at maximum efficiency. But if we put one large engine into a works, that engine would have to work sometimes at only one-tenth of the full load, and therefore at very poor efficiency. So the two cases can hardly be compared. Mr. Williamson.

I do not quite follow Mr. Mavor's statement that the real argument for adopting electric driving is "the possibility of introducing economical plant into the generating stations." I think rather that the centralisation of the plant is the main argument. Whether the plant be old or new, economical or wasteful, within reasonable limits the cost of labour will not be altered. Coal and water are reduced by economical engines, but these two items only represent about half the cost per unit at the switchboard.

The economy of electric driving must be considered in terms of useful work at the machines and tools. Replacing an old and inefficient engine which drives direct to line shafting, by a new engine of high

Mr. Williamson.

efficiency and a dynamo and motors, will not reduce costs so long as the load remains high. It may, however, have a very marked economical result if the load is a varying one and full advantage is taken of the opportunity to cut out shaft and belt losses at times of light load.

There can be no general argument for or against electric driving; each case has its *pros* and *cons*.

I do not mean to suggest that economical engines should be passed over, but I attach more importance to careful attention to the arrangement of machine driving together with absolute reliability in the generating station.

I quite agree with Mr. Selby Bigge. He says that the power-house should be designed in proportion to the whole area of the works—that is, to leave room, as I understood him, for all the generating plant that is likely to be required at any time. That is what we tried to do. We have not only extended the shops, but we have also bought more land—when the first power-houses were planned, nobody could foresee that. The method of allotting space for power-house in recent cases was to take the total acreage of the land, and from the figures which are published in the paper to estimate what is the maximum amount of power required to drive all the machines which we could put into the buildings covering the whole of that ground. Those figures in the paper will be found fairly accurate for works of a similar nature. It is not always possible to get as much space as one would like in a central position to put down the plant. That is why we had to divide it and to have two or three separated stations. Then about the insulation on the overhead wires. We provide a light insulation, as I say, chiefly for the protection of the telephone wires, which have an unfortunate habit of falling, and when they come across the power wires there is trouble and the telephone service is interrupted. After six years we find that none of the light insulation has come off the wires, and it is apparently in a perfectly good state of preservation. The recent machines which we have put down, within, say, the last year or two, are nearly all designed for variable speed. It is becoming much more common now than it was to have variable speed. I think that is chiefly due to our having found out the extreme convenience of it. I have spent a good deal of time looking about for alternating-current motors which possess the quality we have been hearing about of a large range of speed variation, but I have really never come across a practical solution of that difficulty yet. I have been in most of the Continental electrical works and manufactories, but I have never come across a case which was seriously described as a practical solution of the difficulty. I am very pleased to find that every speaker has agreed on the question of circuit-breakers. They were a constant source of worry to me at the works, fuses with a liberal margin are very much better. As regards saving in the works, Mr. Selby Bigge put it down roughly at 35 per cent. Curiously enough, I have worked out a number of cases where I could get fairly reliable data, and I came to exactly the same conclusion that it was between 30 and 40 per cent. You may take it as 35 per cent. on the average when you are dealing with works of this nature. When we started to put down this plant, we had to choose between

Mr. Williamson.

alternating and continuous current. Of course, at that time there was very little comparison between the two.

There is no doubt that improvement has been made in alternating motors, but I do not think that they compare for our class of work—for solid engineering work, where you want a very heavy starting torque in the case of cranes and shop machines with flywheels, which take a great deal of starting, and also with machines requiring speed variation. I think those two points are most important, and I fail to see where the advantage of 3-phase work comes in when you are dealing with short distances, and where, if you use 3-phase plant, you would not exceed the pressure which you use for continuous. I think it is a positive disadvantage, because, if I had 3-phase machinery in the works, I should feel tempted to put transformers in, in order to get two or three different pressures, and by doing so, of course, would throw away a certain amount of energy. I agree with Mr. Allen entirely on the question of clutches. We have used clutches in a number of cases and found them exceedingly good, but six or seven years ago we had a difficulty in getting them. Mr. Fairfax spoke of the speeds we have chosen. We had to choose those speeds, averaging about 600, as a compromise between the excessive cost of low-speed motors and the difficulty of reducing high-speed motors down to the point where you would wish to use the power. This is a very interesting gearing indeed which he has brought forward to-night, but I am afraid that to get only a difference of speed of from 800 to 650 on four pulleys side by side would not meet our requirements in all cases. This model seems to run very nicely, but for most tool operations we require a much wider range of speed. Mr. Russell, speaking of the Silvertown Company, says there are a number of cases where it would not do to put in motor driving and displace engines which are there at present. I quite agree with that in general. In many cases there are operations which are much more economically done by steam-engines, taking into account the capital outlay involved in electrical driving arrangements. In our own works we started with that idea and modified it a great deal, because we found that by putting on every machine at all suitable for electric driving, we increased the load on the generating plant and secured a steady demand for the current, thus reducing the cost *per unit* very considerably all round. When a fresh operation was put on to the power plant, although it might not be done any cheaper than it was originally, yet by increasing the load at the generating station, and dividing the standing charges between many more units per annum, we found it cheapened the cost of production on all the other operations about the works. In considering the cases of applying motors to a works like the Silvertown or any other works, it is very important to take into account whether labour can be saved or not. It is a question of reducing the staff of engine-drivers and firemen to a great extent. It is not so much a question of an isolated engine as of an isolated boiler—that is the trouble that has to be got rid of. With regard to the worm-gearing which is used in the Silvertown works, I have had experience of fairly heavy power worm-gearing under exactly similar circumstances—that is, in indiarubber works. I had tests made there

Mr. Williamson.

of it, and the efficiency came out between 85 and 90 per cent. Ball thrusts were used, and of course it was fairly modern gear, very well made and running in oil, and it had a long life. There was absolutely no fault to find with it for that special work. It is too expensive for ordinary work, I think, and not quite as efficient as spur-gearing. I quite agree, also, that chain-gearing costs at least 50 per cent. more than spur-gearing, but it has so many advantages that I think it is worth paying for it in many cases, in order to get a compact drive.

I did not mean to speak disparagingly of smooth-core armatures, because we have five or six smooth-core machines now of about 250 horse-power, and though they have been running for six years they have not cost anything at all for repairs. But as we can buy slotted armatures for much less money than we gave for these old smooth-core machines, I much prefer to have slotted ones, because they are undoubtedly stronger. In the early days I had a number of cases of the armature conductors being swept round the face of the core, in smooth-core motors, subjected to heavy variations of load. We have had no troubles of that sort with any generators, though in the six years we have had them they must have had a good many short-circuits. Coming to Mr. Scott's remarks, my experience is practically confined to continuous currents, and I have done very little with alternating currents; but as far as my continuous-current experience goes, it is totally different to Mr. Scott's. We do not have to continually renew carbon brushes, and we are practically unaware that there is a commutator on the machine—it gives no trouble. There is one point that Mr. Scott raises, and that is the comparative space occupied by the continuous- and alternating-current motors. Mr. Scott says you can put an alternating-current motor in a space into which you could not get a continuous-current motor. Does that include the speed cone that Mr. Scott recommends for varying the speed? I should think probably not. The question of gas-engine plant was mentioned. It is only recently that we have been able to get a big gas-engine. We are adding some gas-engines now, and if we had work to do again of a similar nature we should put in gas-engines without a doubt. We are at present building some very large generators for a works in Glasgow, which are to be driven by gas-engines at slow speed. When the plant is big it pays to put down Mond gas plant, but if you have got a small plant it does not pay. To reap the full benefit of all the bye-products in connection with the Mond gas plant you must have a fairly big plant to deal with. Mr. Hammond mentions the high consumption of coal. That has troubled me a great deal, but I cannot help it. Those are the figures. I think it is partly due to having small sets, and then in the case of the North Power-house we are non-condensing. Another way I account for the high cost is that we have steam-driven auxiliaries—the feed-pumps and the condensers being driven by steam. There is no doubt that these small auxiliaries when they are steam-driven eat up a great deal of steam, and steps are being taken at the present time to replace this steam auxiliary plant by electrically-driven plant, and when that is done I am pretty sure that we shall get this objection removed.

Mr. Williamson.

I do not think that the load-factor plays such a very important part in fuel-cost. Consider the two cases of a perfect load-factor and that at the Sheffield Works. The first would be represented by a continuous electro-chemical process when the steam consumption would be steadily at its minimum, say 15 lbs. per B.H.P. hour for condensing engines of 500 B.H.P. The load-factor at Sheffield is of such a nature that we can only run generators up to, say, an average of 75 per cent. of full load, allowing a margin for fluctuations in demand. Our steam consumption would not be more than 16 lbs. for the same size of unit. This difference is only about 6 or 7 per cent., and would only raise the coal per unit from 0·3d. to 0·32d. To go further, lighting stations have a far worse load-factor, but their sets do not usually run at a lower mean load than 75 per cent., so that during the time they are on they work as efficiently as the sets in the steel works. No doubt some additional loss is made in lighting stations, by having to light boiler fires and keep them banked waiting for load, but my point is that load-factor affects coal consumption very little, while it affects wages and standing charges largely.

The calorific value of the coal used at Sheffield is 12,720 British Thermal Units, this being a mean of five kinds of coal.

Replying to Mr. Stewart's question as to the means adopted to secure sparkless commutation with weak field, I may state that no special form of pole-tip or commutating device is used; the main principle of design is to make commutation as natural and easy as possible. There is no question that perfect commutation is secured over the ranges of speed mentioned, and that with very little addition to the weight compared with a constant-speed machine whose speed is, say, midway between the maximum and minimum of that of the variable-speed motor.

Mr. Stewart is right in saying that variable-speed motors are not new. I have used them for six or seven years, although it is only within the last four years that I have made full use of the convenience of variations of 200 or 300 per cent. in speed.

Mr. Chatwood says he thinks that two machines working out of ten would represent working conditions more fairly than eight out of ten. If we found that to be the case in our works, we should look out for some new foremen.

The President.

The PRESIDENT: We have certainly had very interesting papers from both these gentlemen; they are papers which I think do an Institution like ours a great deal of good, because they teach the outside world what they ought to know—viz., that electrical current can be used to great advantage in many cases where the public may think its adoption of doubtful utility. It is quite needless, after the full and interesting discussion that has taken place, for me to say anything, because I can see by the way that you have listened to the remarks of Mr. Williamson and Mr. Chatwood, and also to the gentlemen who have discussed the papers, that we are very much indebted to them for what they have done for us. Without further words I ask you to show your appreciation in the usual manner.

The vote was carried by acclamation.

THE RICHMOND-CAREY LIFT.

The PRESIDENT: Before you go, gentlemen, I have to say that Mr. Carey has been kind enough to bring here a model of the Richmond-Carey electric lift. The time at our disposal is now very short, and there is no paper to be read on the subject. Mr. Carey, in making his demonstration of the working of the lift, will give us a short explanation which will only occupy five minutes.

Mr. R. F. CAREY: The lift of which the model is before the meeting is a new electric lift which I have got out in conjunction with Mr. Richmond. The idea of it is to do two things—first, to get a lift which will work automatically, and, secondly, to get one which, as far as we can see, is absolutely safe. I do not know whether any one can point out how it is possible to have an accident with it. I have tried to find out, but cannot do so. There are no attendants required. No one can open the outside doors and fall down the well-hole, because the doors can only be opened when the lift has come to a standstill on the particular floor. That avoids the most frequent cause of accidents. By pressing a button the lift comes automatically to the required floor, stops, the door is freed, the passenger steps in, and, by pressing one of a series of buttons inside the car, directs the car up or down to the floor to which he desires to go. There the same process is followed; the car stops automatically, the door is unlocked, and the passenger steps out. It is worked in the ordinary way by an ordinary motor and gearing.

Mr. Carey then showed the model in operation and explained a diagram which he exhibited.

The PRESIDENT: I am sure, gentlemen, that you wish that I should thank Mr. Carey in your name for bringing this lift before us.

The PRESIDENT announced that the scrutineers reported the following candidates to have been duly elected:—

Associate Members.

William Alfred Barnes.
Joseph Wm. Aberdeen Binner.
William Dolton.
Henry Francis Francis.
Joseph Menmuir.
Albert Edwin Moore.
Geo. Richardson.
Arthur Robert Shapley.
Herbert Vickers.

Associates.

Cecil Edward B. Christie.
Chas. E. F. Evans.
Wm. Hellier Evans.
Robert Pries.
Samuel Scargill.
James Stephen Souter.
Percy Alfred Spalding.
Herbert James Stracey.

Students.

Richard Chas. Hope Dawes.
Henry Arnold Greaves.
Wm. James Lindsay.

LEEDS LOCAL SECTION.

ELECTRICITY SUPPLY FOR SMALL TOWNS AND VILLAGES.

By A. B. MOUNTAIN, Member.

(*Paper read at Meeting of Section, March* 19, 1903.)

The success which has attended the introduction of electricity to all large towns is indisputable, and that it is being adopted for lighting and motive power at an ever increasing rate is also undeniable, but when we consider the small towns and villages we find very little progress has been made, and when we think of the immense number of such places, many without even a gas supply, we must realise that there is still a great field open to the electrical industry, but the fact that so little has been done shows that difficulties and misconceptions exist which are tending to impede the introduction of electricity, and it may be well to consider these, first, from the point of view of influential gentlemen residing in such small towns, whose support is necessary for the introduction of any new undertaking, and, secondly, from the engineers' point of view.

The first difficulty is the want of enterprise or energy which is noticeable in all small places, not necessarily due to want of knowledge, but rather to a desire to leave things as they are. This feeling of apathy is greatly encouraged by the local gas companies, who are, perhaps naturally, in opposition to the rival undertaking, and do not yet realise that the introduction of electricity nearly always leads to an increased consumption of gas.

The second difficulty is the supposed large initial outlay of capital necessary to construct works, the very general idea that such small works must charge a high price per unit, and so cannot compete successfully with gas or oil, and will therefore not be carried on profitably, and will consequently, if owned by a company, pay no dividend, or, if owned by the local authority, become a burden to the ratepayers.

It is perfectly true to say that several small places in which works have been constructed have not been financially successful, and that care must be exercised in the designing of the works and mains to ensure success. The causes of failure would appear to be due to the small towns constructing works upon the same lines as neighbouring large towns, or, in other words, such failures have been due to want of knowledge, but with care in the selection of a system and in designing the works and distributing mains financial success can be assured even on the smallest scale, and the initial capital outlay upon works in a small place should be proportionately less than in a large town where one is compelled to construct works and lay mains of sufficient size to meet the demand which is certain to arise in future years, and which

necessitates a large proportion of the initial capital being unproductive for some years. Then, again, it is wrong to assume that small works cannot sell electricity profitably at a reasonable price per unit. In many small places, both under the control of companies and local authorities, the charge is at the rate of from 4d. to 6d. per unit, and, in some small villages where the supply is derived from local works such as collieries, mills, local electrical engineers, etc., the supply is being given at prices varying from 3d. per unit upwards, and in many cases, where the supply is being taken from the gas or oil plant installed for a private residence, a charge of 4d. per unit would be profitable.

There is also the further fact that the charge for gas in small towns is usually much higher than in large ones, so that the electricity supply would have this great advantage in small places. It is usually found that electricity at 4½d. per unit will be adopted in preference to gas at 2s. 6d. per 1,000 cubic feet.

The third point against local enterprise is the idea that the power companies will eventually supply all such small towns and villages, and will consequently ruin any local undertaking. Undoubtedly, during the last three or four years, a great deal of discussion has taken place, and the idea has been very generally spread that the power companies contemplate supplying over the whole of the areas for which they have Parliamentary powers, but this does not seem probable or possible, commercially, if one considers their past achievements, and the fact that the small villages and towns are so far apart that in most cases the mains required to connect two places will exceed the cost of constructing and working a generating plant. In fact, it is difficult to see what advantage can be gained by taking energy in bulk from a power com-company. In any case consumers will require meters and services, mains will require laying from some central point to such consumers, a building must be provided into which the mains would be carried, and in which the alternating motors and continuous-current dynamos will be fixed. This practically covers all that will be required for a local central station, with the exception that steam, gas, or oil engines would be substituted in place of the alternating motor; in both cases practically the same supervision and labour would be necessary. The difference in cost would be that energy from the power company would probably, in accordance with the latest published information, cost 2½d. per unit, whereas it could be generated by steam or oil engines at from ½d. to 1d. per unit.

The fourth and perhaps most usual difficulty is the cost of obtaining the necessary Parliamentary powers to establish local companies or municipal undertakings, and a further dislike to the stringent regulations of the Board of Trade and the Local Government Board. These difficulties appear to affect municipalities more seriously than companies, but in any case are not such as to cause any trouble when the works are once started. The fact that the Local Government Board will not allow the cost of obtaining a provisional order to be placed to capital account necessitates a charge upon the rates, and the additional fact that the repayment of all money borrowed must commence at once is a very serious point, and greatly retards new works, because it is practi-

cally impossible to get sufficient consumers connected during the first year to bring sufficient revenue to provide the amount required to repay the first annual instalment of capital; consequently this amount, if not provided by revenue, must be provided by rates.

That some concessions on this point might be made by the Local Government Board is generally agreed, and when it is considered that in the case of tramways one or two years are allowed for construction, and that the full revenue from a tramway system commences at once, whereas the revenue from an electric supply undertaking can only grow gradually, it will be agreed that local enterprise is not encouraged.

Engineering Difficulties.

In considering the supply of small towns and villages from the engineers' point of view, it is necessary to try and gather what small amount of data exists, and consider the problems as quite distinct from the supply of large towns.

The expression "small town" should include any place having a population of from 5,000 to 15,000, and "villages" any place having a population of from 500 to 5,000.

There are in Great Britain and Ireland about 500 such small towns, and between 2,000 and 3,000 villages, and very few of these have any electricity supply undertakings, so that there are plenty of opportunities for activity in developing local enterprise.

The chief points which we, as engineers, should determine to enable us to design a small scheme upon sound financial lines are:—

1. The probable number of consumers and consuming devices which will be connected within two or three years, and the ultimate maximum development.

2. The maximum demand which the generating plant will be required to supply.

3. A suitable position for the generating station, the form of motive power and system of generation.

4. The best method of distributing the supply, and the connection of consumers.

The first point is by far the most difficult, and nothing but experience will enable one to estimate at all correctly, but it is most important, because the works should be constructed so that extensions do not mean scrapping plant in future years, and on the other hand the works must not be unnecessarily large, or the financial results will be unsatisfactory during the first few years.

It is also quite impossible to form any correct idea of the consumers who will be connected without first settling the price to be charged; obviously, the lower the price, that is to say, the better the price compares with gas, the quicker will consumers become connected, but this course will also probably result in a loss for the first year or two. There is little doubt that it is advisable to fix the price as low as possible at the start and encourage all classes of consumers.

One method of ascertaining the number of consumers likely to be connected is to graduate the number of premises by their rent or

rateable value, and it will usually be found that the majority of premises rated above a certain amount may, with a few exceptions, be relied upon; the amount selected will vary in proportion to the size of the town. If, however, the electricity supply is in the hands of a company which would adopt some system of fixing prepayment meters and a few lights free of cost, it might be possible to connect a very large number of small consumers. Unfortunately a local authority has no powers under the Electric Lighting Act to charge to capital the cost of fixing wiring upon consumers' premises; some of the larger towns have obtained powers by applying to Parliament, but this course would be altogether too costly to be undertaken by a small place.

The second point is more easily determined. In small places shops do not indulge in a large amount of show, and fewer lights are fixed generally. The maximum demand upon the works would not appear likely to exceed, during the first two or three years, half the lamps connected, and this would gradually be reduced to about one-third of the total lamps connected; this is assuming that electricity is used for street lighting—if not, the maximum demand would be reduced.

The third point, the selection of the form of motive power, has in many cases given the author considerable trouble.

The selection of a site for the generating works is not difficult, if one first decides upon the kind of motive power to be adopted. If steam is to be used, it is necessary to bear in mind facilities for getting in coal, and water should be as near as possible for condensing purposes. If gas is to be used and the supply taken from an existing company, the position of the site must be such that the supply of gas may be easily and cheaply obtained. If, however, it is thought advisable to make your own gas or adopt oil engines, then the site may be selected in the very best and most central position.

In most small towns the disposal of refuse is becoming a more or less serious question, and should have consideration in conjunction with the supply of electricity; this may influence very largely the selection of the form of motive power to be employed, because if Refuse Destructors are to be adopted the heat may be used for generating steam, and the cost of destroying the refuse reduced by the amount which will be paid for the steam used for producing electricity. The steam thus economically produced is of great advantage to the electricity department, as it enables a low charge to be made for energy for motive power purposes.

The form of motive power to be adopted must therefore depend upon local conditions to some extent. The chief point to determine, however, is with which form of motive power the most economical generation of electricity may be obtained, and it may be interesting to give some examples of the different kind of plants which may be adopted for a small town with a population of about 7,000.

The estimated lamps connected during the first two years are 3,000 of 8 c.p., and the estimated connections at the end of about the 10th year 14,000 of 8 c.p. The first instalment of plant would therefore require to be equal to about 60 kilowatts, and might be

divided into one 20 kilowatt and one 40 kilowatt plant ; the latter sized unit of plant being continued as the station developed.

Confining now our attention to the generation only, the works would cost the following amounts, depending upon which form of motive power was selected :—

OIL.

	£
Buildings and foundations...	250
Two engines, dynamos and switchboard	1,175
4 H.P. plant instead of accumulators	125
	£1,550

TOWN GAS.

Buildings and foundations...	250
Two engines, dynamos and switchboard	1,050
4 H.P. plant instead of accumulators	100
	£1,400

PRODUCER GAS.

Buildings and foundations...	500
Two engines, dynamos, switchboard, and producer...	1,375
Accumulators	175
	£2,050

STEAM.

Buildings and foundations...	750
Two engines, dynamos, switchboard, and boilers ...	1,475
Accumulators	175
	£2,400

For the purpose of ascertaining the average cost of generation it may be safely assumed that in the second year 30,000 units of electricity will be sold. The costs will therefore be, approximately, as follows for each form of motive power :—

OIL.

Oil, used as fuel	·5	pence per unit
Oil, waste and stores	·12	„
Labour in the station	·40	„
Repairs	·20	„
Management, rents and rates ...	·37	„
Depreciation, at 4 per cent. ...	·5	„
Interest, at 4 per cent.	·5	„

Total cost of generation per unit sold, 2·59d.

Town Gas.

At 2s. per 1,000 cubic feet, allowing 25 cubic feet per unit.

Gas	·6 pence per unit
Oil, waste and stores	·12 "
Labour in the station	·40 "
Repairs	·20 "
Management, rents and rates ...	·37 "
Depreciation, at 4 per cent. ...	·45 "
Interest, at 4 per cent.	·45 "

Total cost of generation per unit sold, 2·59d.

Producer Gas.

3 lbs. of coke per unit, at 16s. per ton.

Coke	·25 pence per unit
Oil, water and stores	·20 "
Labour in station	·60 "
Repairs	·24 "
Management, rents and rates ...	·37 "
Depreciation, at 4 per cent. ...	·65 "
Interest, at 4 per cent.	·65 "

Total cost of generation per unit sold, 2·96d.

Steam.

10 lbs. of slack per unit, at 8s. per ton.

Slack	·42 pence per unit
Oil, waste and stores	·20 "
Labour in station...	·60 "
Repairs	·24 "
Management, rents and rates ...	·37 "
Depreciation, at 4 per cent. ...	·77 "
Interest, at 4 per cent	·77 "

Total cost of generation per unit sold, 3·37d.

From the above figures will be seen the enormous importance of keeping down at the lowest possible point the capital expended. It may be urged that it is unnecessary to allow 4 per cent. for depreciation, and the same amount for interest, as a local authority can usually obtain twenty-five years for the repayment of its electric lighting loan, and the annual amount to be set aside each year for the repayment of the loan, allowing 3 per cent. for accumulating interest, would only equal 2⅜ per cent., and money can be borrowed by a local authority at 3 to 3½ per cent. ; but it is much better to keep figures perfectly safe, and the larger the amount provided for depreciation the sounder the undertaking will be. It is also doubtful if a company could borrow under 4 per cent.

It will be noticed that in the Oil and Town Gas stations small plants are suggested for running the load from midnight until the following evening. These plants are so perfectly made that they may be safely left to run without any attention, and will be found to be much more economical and reliable than accumulators.

In most small places where gas companies are in existence, it will probably be possible to obtain gas at a lower price than 2s. per 1,000 cubic feet, and then, when the works had been running for a few years, it might be found more economical to use producer gas.

If steam is adopted, the locomotive form of boiler will save a large amount of capital by dispensing with brick chimneys and flues, and it will be advisable to run non-condensing during the first few years. The figures given show the results in what may be called a middle-sized small place; in larger towns producer gas or steam would compare more favourably, while in small villages town gas or oil would have still further advantages.

It is not necessary to discuss at length the system of supply to be adopted. In most small places a two-wire 200 or 220 volt continuous-current system would be most suitable; but in some cases where long distances had to be covered, alternating currents at 200 volts, with step-up and step-down transformers, would be very convenient and simple.

The main thing in designing a generating station for small places is to try and simplify the working arrangements as much as possible, as it will be impossible to employ highly-paid engineers to take charge of the undertaking.

The next point which the engineer must consider very carefully is the method of distribution. Most small places are scattered over a considerable area, and the length of mains per consumer will be much more than in large towns. Consequently a great effort must be made to reduce the cost. This can readily be done if overhead wiring is adopted, and in a small town of a rural character no argument of any importance can be advanced in opposition, while the arguments for overhead wiring are very strong.

1. It is much more economical.

2. More easy to keep in order.

3. Easy to substitute larger wiring when small wires are overloaded.

4. No disturbance of the pavement is necessary to connect consumers or find a fault.

5. The cost of connecting consumer is very materially reduced.

To show the difference in cost between underground and overhead construction let us proceed with the example already considered, and assume there are 120 consumers connected and three miles of mains, the sectional area being ·1 of a square inch. With overhead wiring it would not be advisable to fix such heavy cables in many streets at first, as it could so easily be replaced by heavier cables later on if it became overloaded.

Distributing System with Underground Cables.

	£
3 miles of ·1 single cables, laid in wooden troughing ...	1,290
20 cable connecting boxes...	80
120 service boxes	240
120 services, including meters, fuses, and fixing ...	540
	£2,150

Distributing System with Overhead Cables.

	£
3 miles of ·1 conductors, fixed upon wooden poles...	770
120 services, including meters, fuses, and fixing...	480
	£1,250

If we now consider the annual cost of distribution we see clearly the immense advantage of overhead wiring from the financial point of view.

With underground cables the cost per unit will be as follows:—

Labour	·12
Repairs	·16
Management, rents and rates	·16
Depreciation, at 4 per cent.	·69
Interest, at 4 per cent.	·69
	1·82d.

With overhead cables the cost per unit will be:—

Labour	·12
Repairs	·16
Management, rents and rates	·16
Depreciation, at 4 per cent.	·40
Interest, at 4 per cent.	·40
	1·24d.

If we add the cost of generation—2·59d., the total cost of production with the overhead cables becomes 3·83d. This is for the second year's working. As the demand increased the cost of production would decrease, so that we may reasonably expect to see small undertakings working profitably and charging from 4d. to 4½d. per unit.

It will be noticed that the cost of services, meters, etc., is included in the above figures. It is usual to charge a sufficient amount for meter rent to cover the interest and depreciation upon the capital so expended, so that this item might be neglected, which would still further reduce the costs of production, but on the other side of the accounts will usually be found an allowance or discount if the accounts

are promptly paid, and this amount has been considered to balance meter rents.

The staff required to work the gas-driven plant would be :—

One Engineer in charge	at	£130
One Assistant	„	£68
One Junior	„	£52

These would during the day fix meters and services and carry out any extensions of the overhead wiring, and the time expended upon such work would be charged to capital.

It is impossible to conclude a paper upon this subject without pointing to the senseless opposition of many local authorities, who obtain a provisional order for the supply of electricity and then spend years debating the expediency of starting the undertaking, or who do nothing until some effort is made to start a company, and then object to the order being granted. It would appear that some effort must be made to make the local authorities realise that they are responsible for the backward condition of electricity supply in small places, and that in the general interests of the country they must either take up the business themselves or allow the supply to be undertaken by local companies.

Mr. W. EMMOTT said that he was quite at one with Mr. Mountain in his views generally, regarding the supply of electricity to small towns, and as to the causes of such backwardness. At the same time it was a pleasure to be able to state from his own experience that matters were improving in this respect, and he was glad to say that there was a more healthy feeling springing up. The smaller Urban Districts and towns were beginning to realise the fact that they had a valuable property in their provisional orders and also that they could not go on playing the "dog in the manger" for ever. Ratepayers were awakening and the Board of Trade was beginning to let the small Councils know that they would have to move or let some one else move. Mr. Emmott.

He quite concurred in Mr. Mountain's remarks as to the assistance we ought to obtain from the Local Government Board and the Board of Trade. He had tried in three instances in 1900 and 1901 in which they had provisional orders to get, to induce the Board of Trade to let them insert a clause empowering the local authority to lease or sell motors, and to do other things which came within the province of electric supply, but unfortunately they could get no alteration or assistance from the Board. This was so much a provincial matter that the Leeds section of the Institution of Electrical Engineers ought to do something in forming a Committee to take the matter up in order to bring pressure to bear through the local Parliamentary representatives with a view of getting the Board of Trade to give a little more latitude in this direction, and he intended laying a scheme before the Chairman with this end in view.

In the case of a large town like Leeds the expenditure of £2,000 or £3,000 in order to get a special Act of Parliament was as nothing, but for a small place it was such a serious matter that they could not do it,

Mr. Emmott.

and these small places could not fight against what may be called the anti-municipal trading section of the community, which, he thought, carried things somewhat too far.

Regarding the large power schemes, he did not see what good they would be to small places of say 10,000 inhabitants for lighting purposes, unless it happened to be an exceptional place in regard to a day-load. This opinion was confirmed by the report of Mr. Parshall just issued with the Yorkshire Power Company's prospectus, in which he noticed that a plant capacity of 10,000 k.w. worked out at £52 per k.w. for capital expenditure, while the receipts for current sold came out at £7 10s. per annum. Taking the average price to be obtained for current at 2d., this equalised 900 units per annum per k.w. of plant installed. He had made a theoretical load curve on this basis, and it required no great mental effort to see that the small towns and villages were not likely to be of use in making even the modest dividend of 5·83 per cent.

As to destructors his experience told him that where five tons of refuse can be obtained per day it would pay to put down a destructor, and part of the whole cost of this should certainly be borne by the sanitary department, or this department would have to sink capital in ground for a tip, and often pay more in cartage of refuse to a tip than to a destructor. By letting the electricity department bear the cost of destroying the refuse, and returning the clinker to the sanitary department, that department was benefited while the steam generated was doing good to the electricity department. There was now no difficulty in regard to combined destructor and electric stations. They had got now to such a state of efficiency that it was easy to get guarantees of 40 k.w. per ton of refuse with good engines and dynamos. He had obtained more, but he had no difficulty in getting 40 k.w. per ton if the plant was carefully designed and the whole arrangements carried out on proper engineering lines. He preferred where he put down a destructor station to have a storage battery. It was advisable to destroy the refuse without loss of time and then to store up the energy.

Regarding gas-driven stations undoubtedly there was a field open in this direction, especially where the Council owned its own gas works, but his experience was that the author had somewhat underrated his gas consumption, for to run as he proposed twenty hours out of twenty-four with little or no load, his engine would be running very light, while all the time it was taking gas to drive it, and considering that even with vertical gas engines of the most modern type they could only get a guaranteed mechanical efficiency of about 85 to 86½ per cent. (he could not get any more, depending on the amount of load), if the engine were running for twenty hours, there must be a considerable amount of gas simply running the engine, which would increase the cost per unit for the time during which current was supplied. He had, some time since, got out the return for eight months of a gas-engine station as follows :—

The average gas consumed, current being measured at the switchboard, worked out at 64 cb. ft. per unit. The engines were by a

leading maker, chloride storage battery, 3,500 lamps on the mains, but practically no day load. Mr. Emmott.

The gas cost 2s. 9d. per 1000 cb. ft., therefore it worked out at 2·2d. This was a rather large consumption of gas, but the efficiency of the dynamo was not very high, and there was the loss in storage. He had tried another place, and took a 30 B.H.P engine, and that worked out at an average of 35 cb. ft. of gas per unit. Another test of a smaller engine, 16 B.H.P., at the same place, gave 34 cb. ft. per unit. He could not say why the smaller engine should have come out more efficient than the larger one, but he found that the large engine had got an excessively heavy fly-wheel on one side only, and also a large fly-wheel on the dynamo and a very long drive. It was said that fly-wheels did not take any driving, but this proved the contrary.

As to the advisability of putting in a battery where there was a gas plant, a battery was required in order to save running the engine with no load. It paid to have a 30 per cent. loss in the battery, together with interest and sinking fund charges, rather than to keep the engine running night and day. Moreover if the engine were of the "hit and miss" type the battery was almost a necessity.

Gas companies being under no obligation to supply gas for power purposes, but only for lighting, the thermal efficiency varied considerably, and the speaker had found it as low as 400 B.Th.U. per cb. ft.

At Hebden Bridge they were putting down a gas-driven station on lines which he believed were quite new. The Council owned the gas works, having bought out the local gas company, and among the plant was a Glasgow and Humphrey water-gas plant, which cost about £5,000, but with the present comparatively low price of coal and for other reasons this plant was practically idle, and in order to provide work for it, the question of power gas had been carefully considered. The Mond plant was found too expensive for a small place, as other gas plants would do the work cheaply and satisfactorily. In order to settle practically the utility of the Glasgow-Humphrey plant a gas engine had been put down and run at different loads up to 48 B.H.P., the carburetting process of the plant not being used, as the cost of the oil would bring the cost of gas beyond that of gas produced by other water-gas plants in the market and therefore the plant was used purely as a water-gas generator.

The result of experiments extending over some three weeks had resulted in the Council deciding to utilise the plant. The tests were most carefully made, the engine being braked on the fly-wheel in the usual manner and indicated at the same time. The gas was metered into the engine and the thermal efficiency of the gas regularly measured by a Junker's calorimeter and reduced to standard temperature and pressure, the coke was weighed into the producer and the gas passed into a large holder. Briefly, the result was as follows: The gas committee had arranged to sell and deliver the gas to the electricity department at 6d. per 1,000 cb. ft., which left a good profit to the gas committee. Guarantees had been obtained from the engine builders to give one kw.-hr. per 60 cb. ft. of gas, the thermal efficiency of which averaged 244 B.Th.U. per cb. ft. The engines were of the four-

Mr. Emmott.

cylinder type, 250 B.H.P. direct-coupled, and to run at 250 R.P.M. As the gas was somewhat richer in hydrogen than some of the producer gases, the piston as well as the cylinder had to be water-cooled to prevent heating and pre-ignition.

As to Mr. Mountain's suggestion, he should be a little nervous about leaving a plant to take care of itself all night, and was afraid it would often be awkward if the consumer had no other illuminant to fall back upon.

As to overhead wires. In very small places overhead wires might be put in, but in his experience they were not entirely satisfactory. He had run from August, 1890, to 1893 with overhead wires, in Halifax, at a pressure of 110 volts for the central part of the town and for the outer area at 1,200 volts transformed down to 110. These overhead wires were a continual source of anxiety and the upkeep was more than that in underground work. He would prefer to see how he could reduce other costs, and lay the wires underground. He would not go to the expense of putting down troughing, but would run the risk (if any) of putting down lead-covered armoured cables. The cost of opening out and filling in the ground and making good pavements in country places was not so serious as in a place like Huddersfield. The roads could be opened out and filled in for about 1s. per yard.

He ran the National Electric Supply Company's Preston lighting for about twelve months overground on pitch-pine poles, but was glad when they had to be taken down. The engines were of the semi-portable type, suggested by Mr. Mountain, and were made by Marshalls, of Gainsborough. They were very satisfactory, but the coal bill was high.

Mr. Wilkinson.

Mr. G. WILKINSON said that the supplying of small towns opened up a very large field, the fringe of which had hardly yet been touched. A scheme might be prepared for a small area and presented in the best manner, but the authorities nearly always turned round and asked where a similar one was to be seen; and it was natural that any Town Council should hesitate until they could see something like the one proposed. This he thought largely accounted for difficulties 1 and 4. The principal reason that had delayed lighting was the visionary one that District Councils had as to the grand time that was coming when the Power Companies would be able to give them power practically for nothing.

It was his duty not very long ago to approach the Yorkshire Power Company on behalf of a District Council with regard to terms of supply. They asked for a minimum supply of 25,000 units at 3½d. per unit; from 28,000 to 125,000 at 3¼d. Up to 187,500 at 3d. (It would be a rather large village which would take that.) Up to 250,000 2¾d., and over that 2½d. per unit delivered. To these must be added losses in distribution.

In reply to a question by Mr. Mountain as to what they would do with the supply the speaker said that they (the Power Company) proposed to supply at a given fixed point at this rate, and as a concession the District Council was to take the bulk of the energy and deal with it as they pleased. He found that to this item must be added £8,500 to

£9,000 in putting down mains, house services, meters, buildings, etc. An engineer and manager would have to be engaged, and all the risk of bad debts and the like would have to be taken, and in fact, except for the stoking of boilers, the entire business of supply would have to be undertaken. In the case of villages the whole of the capital outlay must be most carefully spent; there was no margin to work upon, as was the case in a large area where the lighting density was fairly heavy. Mr. Wilkinson.

He did not think that the future lay with destructors, unless there was a strong reason from a sanitary point of view, as the initial outlay was very large indeed, and the advantages did not warrant it. He thought the refuse should be put on the land rather than burnt, as there was in many of these areas plenty of tipping ground.

It was difficult to say what form the combustion engine would eventually take, but he did not think steam had any chance. He thought there was something to say in favour of oil and town-gas rather than producer-gas and steam. In the paper, 10 lbs. of slack per unit at 8s. a ton was mentioned, but he did not think that there were many places where it could be obtained at that price, as there are many villages where cartage would cost you 2s. 6d. per ton. Regarding town-gas figures, the price was put down at 2s. per 1,000 cubic feet. In Harrogate the least it could be obtained at was 3s. 2d., less 10 per cent.; in Otley it was 3s. 4d.; Wells was 5s. 3d. and Tadcaster 5s. 3d.; and he, therefore, thought that this figure should be increased very considerably. Again with regard to combustion engines he said that he knew one of the big supply companies was just concluding a contract for a 1,000-kilowatt internal combustion engine rather than increase their boiler and steam plant.

As to oil-engines. Oil was given at 0·5d. per unit, but he thought it could be done for very much less. He should be inclined to put it down at 0·23 to 0·25d. Another point with regard to the 4 H.P. plant to be used instead of accumulators. His opinion was that it would not be safe to allow it to take care of itself entirely. Up to a few months ago he produced his own electricity at home by a 3½ kilowatt dynamo driven by a Paris-Singer gas engine. Accumulators were not used, and the cost of running did not exceed the cost of lighting by gas. Accumulators need not be very expensive, and would be a safer arrangement, the station could be shut down entirely for daylight hours, and they would give an economical load while such plant was running, and he would very much prefer to use them.

Mr. Mountain said "the estimated lamps connected during the first two years are 3,000 of 8 c.p. . . . and the first instalment of plant would therefore require to be equal to about 60 kilowatts." It did not appear from this that any spare plant was provided, and he would be glad of further information because it was always understood that a certain amount of stand-by was an absolute necessity, and he therefore thought that the capital outlay would have to be increased for this stand-by plant.

He quite agreed with Mr. Mountain as to the future of overhead rather than underground distribution for thinly populated areas, as it was very much easier to look after the distribution of overhead than

Mr. Wilkinson.

underground cables, and there were no expensive joint boxes as in an underground system.

Mr. Harris.

Mr. HARRIS said that towns' refuse was now being largely employed in the production of electricity at a cheaper rate than any other method in existence where fuel was to be used, and the consulting engineers in general were now recognising this fact. Professor Kennedy, for instance, had at the present time 4 or 5 stations where he was recommending a refuse destructor because of its cheapness. From a sanitary point of view the refuse should always be destroyed, and corporations and councils had come to the conclusion that a destructor was necessary and that they might just as well have a return for the cost of the outlay in the production of electricity. This was an important factor in determining the electric light stations being put down at Cleckheaton and Shipley. He was of opinion that it would pay all towns, and small towns in particular, to take up the subject and bear the whole cost of putting down the refuse destructors in connection with electric light stations.

He gave a comparison between the cost of generation by coal and by refuse. Taking an average cost of fuel and wages, and allowing in each case only one man for the boilers, he showed that the difference was very great indeed. Taking a yearly output of 87,000 units the average price per unit (taken from the *Electrical Times*) was 1·353d. With a refuse destructor, including interest, sinking fund and repairs, it was 0·376d. Again, with a coal plant, between 87,000 and 131,000 units per annum, the cost was 1·053d., while with a refuse destructor plant it was 0·391d.

The engine-room charges and interest on the electric light station were left out. Taking again a larger plant of 131,000 to 175,000 units, the cost for coal, firing, and one man was 0·939d. as against a destructor station 0·295d., and coming to a still larger one of 350,000 units coal, firing, and one man 0·916d. as against refuse destructor 0·264d. It was certain that only the largest stations in the country were producing electricity with a fuel cost of anything like 0·26d. The figures would allow for ample margin for interest and sinking fund charges, and the working results in different places confirmed these figures.

At Darwen for the last financial year the refuse destructor effected a saving equal to £1,050 in coal, although they were working non-condensing, and if they had had an economiser the saving would have been very much greater. It was quite the usual thing to get 40 units per ton of refuse, and in some cases over 60 units, and he expected to hear of still more. He thought that it would pay station engineers generally to push the subject more than they are doing, and advocate the use of town refuse instead of coal.

Mr. McLachlan.

Mr. McLACHLAN said that there seemed to be some misunderstanding with regard to the cost of gas in small villages. It was produced in York for 1s. 10d. per 1,000 cb. ft., whereas it was quoted as at 3s. 2d. in Harrogate and 5s. 3d. in Tadcaster. If an agreement were made with the gas company it was probable that it could be obtained at from 8d. to 1s., which reduces Mr. Mountain's figures by 50 per cent. With regard to producer-gas, Mr. Mountain was on the right side, as

guarantees could be obtained to produce a unit for 2 lbs. of coke, as against the 3 lbs. given in the paper; and, again, coke could be obtained at from 8s. to 10s. per ton from many gas companies, as against the 16s. given in the paper, and this still further reduced the cost. He thought that the repairs might have been brought down a little more. If all these things were reckoned together it would be seen that electricity could be produced for about 2d. per unit, which was a saving of nearly one-third. The figures given by Mr. Emmott, viz., 64 cubic feet per Board of Trade unit, were rather peculiar, because any good type of gas engine could now be reckoned to consume something less than half of that. Passing on to the question of power he said that nobody seemed to have thought of the fact that electricity could be used for power in small villages, although not to any large extent. Mr. McLachlan.

Mr. M. B. FIELD said that he could not agree with Mr. Mountain that the total cost per unit would come out at 3·83d., and that there would be a good profit at 4½d. with a plant of the size contemplated by him. The question as to whether it was going to pay to supply small villages from a large power station depended on many things, amongst others, on the size of the village, and the amount of power required; also upon whether power could be conveniently tapped off from a line arranged to supply, say, a very much larger village somewhere else. The question was largely determined by the matter of overhead lines or underground cables, and he did not see why there should be any uneasiness whatever with regard to the former. Mr. Field.

They were universally adopted in the United States and Canada and on the Continent, and he thought that when the Board of Trade had sufficiently advanced to allow them that there would be a far better chance of supplying small towns and villages from the large power stations at a comparatively cheap rate.

In regard to the objection of Mr. Mountain to the large power schemes on the ground that buildings would be necessary and machinery would have to be erected, attendance provided, etc., he could only say that in America lines were run for many miles and absolutely no attendants were provided for at the far end for carrying out the transformation or distribution of the energy.

Mr. E. A. PARIS said that as one of the oldest missionaries he had passed through the various phases of the several controversies — continuous-current *versus* alternating-current, accumulators *versus* running plant, and large central stations against small isolated plant—and he was certain that the small isolated plant with a highly efficient prime mover would win the day. Mr. Paris.

He thought that the oil-engine had a very great future before it, more especially for the kind of lighting treated of by Mr. Mountain. He agreed with the author as to the senseless opposition of many local authorities, who obtained a provisional order and then did nothing until some effort was made to start a company.

Mr. S. D. SCHOFIELD said that he considered Mr. Mountain had taken some very low costs, as there were many stations even in the coalfields where the coal cost exceeds 0·42d. per unit. If stations with from 500 to 800 kilowatts installed could not get below 0·6, and in some Mr. Schofield.

Mr. Schofield. cases 0·8 or 0·9, how could a country village be expected to get to 0·42 or anything below 0·5d.? In some cases it would be more economical for a private company to start a supply in a village without obtaining a provisional order, as they would be in a better position owing to there being no restrictions against overhead conductors. The success or otherwise of a small station, quite as much as the success of a large one, depended upon the *esprit de corps* of the staff. He thought that the engineer that would make a small place successful would be one that was always out canvassing and who would act as consulting engineer for the wiring of installations and would advise upon the installing of motors in order to help to get a motor load.

Mr. Wallace. Mr. G. S. Wallace said that before wires were erected permission would be necessary to carry them over property, although, of course, if the District Council were doing the work the difficulties would not be so great on the main roads, but they would still have some difficulty in going over private property, and with a private company this would be more noticeable and would increase their annual charges very considerably. Again, he thought that there would be a great fear of the wires, as the demand increased, becoming very unsightly, and that in consequence objections would be raised, which would in many places lead to their being removed. He was surprised to see that the repairs in each case were taken at 0·16d. per unit, as he was sure that, if the underground system were properly laid, the repairs should not be so high as for the overhead system. He noticed that the cost for depreciation for underground cables was 0·69d., whereas for the overhead it was 0·4d. Seeing that poles had to be taken down and possibly erected elsewhere and that they required renewing at certain intervals, he thought that the depreciation would be greater with overhead cables. If there were at all sufficient margin to allow for underground cables in the initial arrangements of the plant he should certainly recommend them rather than aerial wires, because when a good supply was obtained the aerial cables would have to be replaced by underground conductors.

Mr. Broadbent. Mr. Broadbent said that he had a small private plant in which the cost of production in gas came out at 0·75 per unit, but the accumulator depreciation brought it up considerably. He supplied energy to friends at 6d. per unit and charged them 15 per cent. per annum on the cost of mains. He found that it was best to run his gas plant at the full output and use accumulators.

Mr. Brook. Mr. Brook said he could speak with actual experience as to the reasonable figures given by Mr. Mountain. He gave some particulars of a gas-driven plant put down by him at Brighouse. Over 4,000 8 c.p. lamps were connected to the mains and 84 brake h.p. was installed and a storage battery was also used. The revenue from the sale of current was about £550 a year, which works out at about 1s. 9d. per lamp. The units sold were 23,000, which could be increased by applying a little encouragement. Current was charged for at the rate per unit of 6d. for lighting and 5d. for power. Owing to the fact that insufficient plant was installed to take the maximum load the battery had to take a large share of the supply, and the cost per unit supplied was fairly high. Gas was charged at 2s. 9d. per 1,000 cb. ft. from

the town mains. He thought that the power companies would find a great difficulty in supplying most of the small towns and villages. He thought that the item for repairs in the four cases given was rather high and should be brought down to one-half. With regard to overhead wires, during the whole six years that he had charge of the Brighouse plant they required no supervision whatever, and he never had any breakdown owing to the failure on their account. Mr. Brook.

Mr. A. L. C. FELL drew attention to a rather misleading point on page 1018, in which it was stated that public companies would supply at 2½d. per unit, whereas it could be generated (it was said) for ½d. or 1d. On page 1021 it was shown that at the very best it could only be produced for 2·9d., and he did not see how these figures agreed with one another. Again Mr. Mountain stated that in a case of a tramway undertaking the revenue commenced at once, whereas the revenue from an electric supply undertaking could only grow gradually, but he did not think that this was quite correct, as, for instance, in Sheffield the revenue had gone up considerably with the same number of cars running. Mr. Fell.

With regard to the question of steam generation he thought ten pounds of slack per unit a great deal too high, as five or six pounds per unit was quite sufficient; and, again, slack could be obtained for something like 6s. per ton, as against the 8s. given in the paper.

He did not see any reason why the Board of Trade should not consent in the case of a small village to do away with the present regulation to the effect that the plant should have to run all night, as he thought it could be shut down at eleven or twelve o'clock, and if this could be done there would be a chance of running the plant at a considerably lower cost. He thought that the local authorities did not take up the question of supply because of the misleading statements which were made about the large power companies, and they did not trouble to inquire as to whether they could not supply themselves more cheaply.

Mr. BAKER (*communicated*) thought that the author's proposal to work a small plant all night without attention was a bold stroke, but at the same time it was warranted by experience. He himself had frequently, in a small private plant, left the engine working all night charging accumulators, and he did not remember that on any single occasion was there any trouble. Mr. Baker.

He differed materially from Mr. Mountain concerning the value of electric power supply companies, as electricity supply became a simple matter for a local authority when the generating works were dispensed with and the problem was simply that of purchasing in bulk and retailing at a profit.

In the paper attention was directed to the employment of motor-generators, but a large volume of the business of the power supply companies would be done through stationary transformers supplying alternating current. He thought there would be a reduction in the cost of the distributing mains owing to the central position in which such a transforming chamber could be located. Again it might frequently be practicable to use one generating station for several small towns close together.

Mr. Baker. He thought the author was right in eschewing condensers in connection with small steam generating plant, unless there happened to be an available stream of water sufficient to work an ejector condenser. The use of a destructor would very materially increase the capital cost in a small system, and a reasonably large accumulator must be added. The most suitable towns for the combination of refuse-destructors and electrical works were those having from 10,000 to 30,000 inhabitants, the limiting number being a sufficient population to provide refuse, and on the other hand a population whose demands are within the range of an accumulator, of which the prime cost was a determining factor. He thought it would be difficult to find an example of 30,000 units per annum being generated at a total cost of 2·59d. per unit, though the figure might be obtained.

Some slight advantage was obtained by pushing the supply voltage as high as possible, particularly when accumulators were not employed, and he thought that the 200 to 220 volts should be made 230 or 240 volts at the consumers' terminals.

Mr. Cruise. Mr. E. G. Cruise (*communicated*) wrote that the question was of undoubted importance at the present time to electrical engineers, companies, local authorities, and to the industry generally, as the list of large and important towns in the United Kingdom where a supply of electricity had not been already inaugurated or arranged for was fast becoming exhausted. It was, however, somewhat alarming for the financial outlook of the electric power companies to read the confirmed opinion of the author and many of the engineers joining in the discussion that these companies would have no field whatever for their work of bulk supply amongst the small towns and villages. When these power schemes were before Parliament for the first time in 1900, the evidence submitted to the special committee which first sat to deal with the schemes was largely directed to show that only by the sanction of these power companies could the small towns ever hope to obtain a supply of electricity at a rate profitable to consumers. Parliament was impressed with this argument and the evidence which supported it; it destroyed the opposition evidence, and there was little doubt but that it was in large measure responsible for the passing of the Pioneer Act, the County of Durham Power Scheme. The precedent once set, the subsequent Acts were more easily obtained, and the evidence referred to was repeatedly quoted in the progress through both Houses of the multitude of Power Acts which had now become law. The special committee above mentioned consisted of eight instead of the usual four members, and had been chosen to include some of the best known business men and financial experts of the day, so that due weight must be given to their judgment regarding the schemes. For the purely engineering evidence they were, of course, necessarily in the hands of the electrical engineers who gave evidence. The underlying principles, however, of the Power Acts were in such large measure principles of financial economics, that it may be taken that their passing by Parliament was tantamount to conviction as to their benefit to electricity consumers in the lesser towns and in outlying villages.

He had no doubt that the evidence before the committee was also well known to Mr. Mountain, but he had perhaps lost sight of the fact that the present rates offered by the power companies were in no sense indicative of the ultimate rates which they would be able to offer. Obviously so long as their load-factor was not vastly more favourable than that of the local supply station, they must commence by rates which would secure them against working at a loss. Even with these initial rates, however, there would seem little room for doubt that they would be widely accepted by the authorities proposing to distribute in the small towns and villages. One point, however, to which Mr. Mountain very rightly referred was the absolute necessity of obtaining sanction from the Board of Trade to having overhead transmission lines, and if this applied to the local distribution, assuredly it applied with double force to the trunk lines of the power companies. This would seem a point to which the power companies had not, so far, given sufficient attention. The explanation might lie in the fact that cable companies were largely interested in the power companies. Agitation on the subject had been developing lately, and even in 1900 a special committee of the London Chamber of Commerce had been appointed to approach the Board of Trade on this subject, and a full report dealing with the question of overhead wires and other questions regarding the economic aspects of the carrying out of the Power Acts, was issued by the Committee. So far no general concessions had been made, but the Board of Trade was undoubtedly now more disposed to deal favourably with the question of overhead transmis-mission, a system in universal use except in the United Kingdom. He ventured to think that the wholesale laying of underground power cables in these schemes at costs of and above £1,000 per mile per 1,000 k.w. cable would wholly defeat the ends and destroy the financial success of the power companies. Mr. Cruise.

But whether the power companies prospered or not, or whether they offered rates far below those obtainable from isolated stations, there was no doubt that there would always remain small and trucu-lent towns where the local authority, or even perhaps a company, would insist on putting down their own generating plant, and it would be in the consideration of such cases that Mr. Mountain's paper would have immediate application. Further than this, there would be many such towns where power companies would have no trunk mains for years yet, if ever, and such places would require a pioneer or perma-nent isolated plant.

Regarding, therefore, the actual questions arising out of the paper, he ventured to suggest a few points. From personal experience of an Inquiry held recently by the Local Government Board for a loan of £6,000 for electricity works in a very small town of 4,000 inhabitants, he was able to say that in such cases the Local Government Board would probably not consent to a sinking fund for repayment of the loan. In the particular case in question they absolutely refused to sanction any other scheme of repayment of the loan than the yearly repayment in cash of the total sum of the loan divided by the number of years it was to run. Thus, the best terms obtainable being a period

Mr. Cruise. of twenty-five years, it was evident that an initial annual charge of 4 per cent. on the capital of the undertaking must be allowed for as against the figure of 2⅝ per cent. submitted by Mr. Mountain. Taking interest at 3½ per cent., we arrive at a total of 7¼ per cent., thus leaving practically nothing for depreciation in Mr. Mountain's tables, and the Local Government Board are very exacting in the case of small schemes for some prospect of such provision. To meet the case, therefore, under the circumstances the price must be raised above the figures given in the tables.

Regarding more especially the producer-gas figures, it was very doubtful whether for such small plants as those in question manufacturers would give any satisfactory guarantee as to the quality and continuity of the gas generated if coke alone were used. The figure of 3 lbs. of coke per unit sold seemed altogether too low, seeing that in the case of Walthamstow a very successful and typical producer-gas station, where the sets were 75 k.w. output each, and best pea-nut Anthracite coal was used, that the figure per unit sold was about 3·2 lbs. of fuel. In the case of really small towns and the proposal to use town gas where available, it would seem that the figure of 2s. per 1,000 c. ft. is too favourable. This in many cases would undoubtedly be below the cost price of making the gas. In the town above referred to the price was about 5s. for any purpose, and this would appear to be a not uncommon figure in very small towns. In such cases town gas was out of the question. Regarding the overhead distribution wires, the Board of Trade would only so far give a provisional sanction for five years, and this not in all cases, and apparently if wooden poles were proposed, the Local Government Board might shorten the period of the loan. The proposal to have an all-night running of the plant with a small set was a novel and interesting one, but it appeared to be very desirable, especially in a small station, to have a small battery at least, to give the necessary light in case of a breakdown. Such accidents would happen to small plants, and the difficulty was largely increased if no good source of light were available for immediate inspection of the various parts of the plant.

Mr. Mountain. Mr. A. B. MOUNTAIN said that he would reply to the points in the paper as they occurred, and not to the individual speakers. Taking first the considerations that appealed to the influential people, the difficulty was that one must somehow persuade the people who live in the district that one can give them a supply at such a cheap rate that they would adopt it, and that the undertaking would be financially successful.

In large cities like Leeds, with all its conveniences, he did not think they appreciated the backwardness of the small places. There were thousands of places in England where there were no street lamps, and no effort whatever was made to light the houses, and in those places small plant could be put down and run at an exceedingly low rate. In a country place a small gas engine could be put down and allowed to run alone all night to supply, say, 50 lights, which was all that would be required. Engine lubrication was now so perfect that there was not

the slightest difficulty in letting them run by themselves for 12 hours. Mr. Field put the case for the power companies, and, assuming that the power companies could supply the works here at a cheaper rate than the works could provide power themselves, Mr. Field was no doubt right, but an examination of figures showed that the cost of producing energy in mills was only something like 0·2d. to 0·3d. per unit. It seemed impossible for any power company to persuade the owner of that works to scrap his steam plant, and put in motors, and take the supply from them, even if they could come to that price, and Mr. Field would agree that it must be many years before they could supply at a price anything like that. Further with regard to power companies, he said that the distributing authority must have some central point or have sub-stations for distributing, and to which the power companies would bring their supply, thus leaving the District Council with the whole of the cost of the distributing services, and mains and other items, including management. He did not think that there was the slightest possibility of the power companies ever helping in any way in the supply for small places. Mr. Mountain.

With regard to the criticism of the figures, he thought that he had not under-rated the amount which would be required to run the works; the figures were taken from certain engineers who had gas-plants under their control. It was quite possible that the average figure would be slightly higher than 25 cb. ft. per unit. If the figure was altered from 25 to 30 cb. ft. per unit and the price of gas reduced 6d. he would be on the right side, and eighteenpence per thousand was quite high enough.

Mr. Emmott was very severe on the question of overhead wires, but if he were given the opportunity of pushing electricity he (the speaker) thought that he would agree with him that ½d. or 1d. per unit in the cost made all the difference between a scheme succeeding and failing, as the question of cost in a small place was far more serious than in a large place. In a small place the working-class had to be supplied, and therefore the very cheapest system must be used, and he was convinced that if we went in more for overhead wiring we should find the simplest way of getting over the difficulties. He found that the repairs themselves to underground mains were not expensive, but when the cost of taking up the roads and also of interference with the traffic was considered, the item was a very serious one.

In the case of overhead wires put up firmly on poles, repairs could be undertaken by anybody without specially skilled knowledge, and they were easily accessible in case of a fault occurring, whereas in the case of underground mains, there was trouble with the District Council if it was a private company, and friction between the various departments if it was a Corporation.

If destructors were adopted, the first thing to do was to encourage in every possible way the adoption of electricity for motive power purposes.

Mr. Emmott mentioned small batteries, but if there was one thing an engineer must fight against, it was the employment of small batteries, and with batteries there must be some one who really understands

Mr Mountain.

what he is doing, as there are more batteries destroyed from want of knowledge than probably anything else, and he was therefore suggesting the employment of small engines to replace batteries, and he felt certain it would reduce the costs considerably.

Mr. Fell has drawn attention to the statement that the cost of production would be ½d. or 1d. as against 2½d. if purchased from a power company, and then points out that the cost of production as shown in my paper is 2·9d. This figure includes management, depreciation and financial charges, all of which will require adding to the 2½d. paid for the energy.

Mr. Cruise has stated the case for the power companies very forcibly, but beyond obtaining powers these companies appear to have made very little progress, although they have effectually stopped the introduction of electricity into the small towns and villages which are now reconsidering the matter, and are likely to do so for many years, thus blocking progress.

It does not matter to a local authority whether the capital is repaid by annual instalments or by means of a sinking fund, the total amount to be provided annually is practically the same.

CALCUTTA LOCAL SECTION.

ON THE PRESERVATION AND PACKING OF PLANT FOR AND IN BENGAL.

By PAUL BRÜHL, Member.

(*Abstract of a Paper read at Meeting of Section, March* 27, 1903.)

After an experience of over twenty years in the "care of plant in hot and moist climates," the author refers to the nature of the adverse climatic influences which have to be combated by those in charge of laboratories or central stations, as being mechanical, physical, chemical, and biological.

In the "mechanical" he includes the subject of packing and care in transportation. He regards some conditions in respect to handling of cases containing scientific instruments as unalterable. As regards design he says:—

"Ample and efficient provision should always be made for securing the coils of suspended-coil galvanometers, the magnetic systems of Kelvin and Helmholtz galvanometers, and other loose or oscillating parts of instruments. There is absolutely no sense in the manufacturers fitting on the suspension, and not taking precautions to prevent the suspensions getting broken, before the instruments reach their destination. An ideal which designers ought to keep steadily before their mind's eye is one which Clark Fisher refers to in his book on the potentiometer: an instrument should be so designed that, provided it is properly packed, it should be possible "to throw it across the room with impunity or even to send it by rail in the United States." Portability and security during transit is a condition which most instruments sent out to this country ought to satisfy.

"In machines, sections which give rise to injurious stresses after casting, or such as create lines of weakness along which concussion is likely or certain to produce fracture should be carefully avoided, and pins or bolts or screws which hold parts in position should be designed of a sufficient cross-section to prevent shearing taking place. Some time ago I received an electric motor with the insulation of the wires on one of the end faces of the armature scraped off and the wires partly cut into by some part of the frame. The cause of the mischief lay in a pin which had the function of keeping one of the shaft bearings in position having been sheared right through, probably in consequence of the case containing the motor having been dropped from a railway waggon or into a ship's hold; and a trifling difference in the design of the bearing would have prevented the accident. It would be a good thing if every designer of instruments and machines manufactured for export made himself intimately acquainted with the special conditions

of transport. Personally I believe that, with proper design and proper packing, accidents to instruments need hardly ever occur except in the case of a railway collision."

On the subject of packing—which is an engineering one, and of moment as affecting successful exportation—he says:—

"Most of the larger firms of manufacturers of physical and chemical apparatus have evolved, on the basis of their own and other people's sad experiences, methods of packing which in the majority of cases prove fairly efficient. Of late years I have only rarely received articles in a broken condition; but then I make it a point to deal only with first-class firms. Very effective is a description of wood shavings, consisting of very thin, very long, and very narrow strips which seem to be specially manufactured for the purposes of the packer.

"It is self-evident that parts should never be lying loose in their box. One of the worse sins of commission on the part of a packer is to pack very heavy and bulky articles in the same case with delicate parts; and yet that is done again and again, as if the packer considered the heavy parts to be specially designed to triturate the delicate parts into a fine powder. All heavier parts should be tightly fastened down by screwed-on battens; and if it is found unavoidable to pack smaller articles in the same case with larger and heavier ones, they should be packed in separate small boxes. All this seems simple and self-evident; but unfortunately sufficient attention is not always paid to these details, and it is astonishing what thoughtless blunders are sometimes perpetrated by the packer."

On the subject of temperature he says:—

"It does not appear to me that the higher temperatures of the tropics and sub-tropics, taken by themselves, play a very important part in connection with our subject. It is doubtful whether any dynamo has ever been injured by being run under full load, although the starting temperature of armature and field-coils has been say 100 or even 110 degrees Fahrenheit, and therefore 20 or 30 degrees higher than the initial temperature would be in England. There are only a few instances known to me of the higher Indian temperatures causing temporary or permanent trouble. One case occurred with one of Lord Kelvin's current balances, in which, during the first hot weather the coils commenced to sweat out some of their paraffin, causing the moveable coils to stick. A small quantity of the more fusible paraffin having oozed out, the remainder having a higher point of fusion remained behind in the solid state, and the balance has been in first-class working order ever since. But it is advisable for manufacturers of apparatus in which paraffin is used for insulating certain parts, to use only paraffin of high melting points in apparatus meant to be used in tropical countries.

"It is possible that the higher temperatures of the tropics have something to do with the dust which may happen to lie for some time on varnished parts of apparatus becoming ingrained in the coat of varnish and spoiling its appearance for good. The only remedy in this case is frequent dusting and keeping the apparatus under cover when not in use."

The effect of high temperatures on chemical agents is discussed as follows :—

"It is different with higher temperatures acting in conjunction with chemical agents ; in this case the influence of temperature ceases to be negligibly small. It is well known that the time-rates at which chemical actions proceed are not only generally speaking functions of the temperatures at which they happen to take place, but they are often rapidly increasing functions of the temperatures and are therefore frequently represented by curves which at first are nearly horizontal, but beyond a certain point curve rapidly upwards. Unfortunately hardly any precise data are available on the relation between temperatures and the time-rates at which such chemical actions take place as the rusting of iron, the formation of verdigris, the action of nitre on various substances interesting to the electrical engineer, the chemical changes which lubricating oil and allied substances undergo in contact with the atmosphere, the action of carbonic acid on various silicates, the action of atmospheric ozone."

The rapid rusting effects in the rainy season are not much prevented by the process of "blueing." For instruments the author has used Vacuum Company's spindle oil laid by means of a brush as a protecting covering. The use of this on the steel parts of exported instruments, the oil being first carefully tested for the presence of acid, he strongly recommends. He recommends that all swinging parts of fine balances and accurate sets of brass weights should be platinised. He objects to gilding ; he prefers phosphor bronze to steel where suitable, and in balances, used in electrolytic work, knife-edges should be of agate.

"Aluminium, provided it is pure, appears to stand the tropical climate tolerably well ; some aluminium, however, becomes quickly converted into hydroxide, and on the whole I do not advise the use of aluminium for parts of instruments ; of course where special lightness is required, the use of aluminium may be unavoidable. There is little trouble with German silver and platinoid. Stretched Iridium-silver wire, as sometimes used in meter bridges, invariably snaps. Bare manganin is not quite climate-proof and requires careful watching. A peculiar change takes place in the suspension strips of the D'Arsonval galvanometers of some makers. After a short time one finds the resistance of the galvanometer to increase rapidly, until it nearly reaches infinity. On examination one finds the strip converted into an exceedingly fragile thread of oxidation products."

Another marked source of trouble are galvanometer mirrors. He says, "I have repeatedly received galvanometers with the silvering of their mirrors either cracked all over and portions of it flaked off or rendered useless by tarnishing. As the best temperatures for silvering such mirrors lie about 20° centigrade, the temperatures ruling in India are usually too high for an attempt to re-silver one's mirrors one's self to prove an unqualified success.

"One of the most powerful corroding agents employed by nature is carbonic acid. We are accustomed to look at carbonic acid as a weak acid ; at least, that is what elementary books on chemistry tell us. Of course, it is weaker than various other acids ; but in many instances it

is weak only because it is volatile—volatility is not usually compatible with strength—or, it is weak because in an aqueous solution prepared under atmospheric pressure it is exceedingly dilute. But when the acid is more concentrated under the action of high pressures, the effect is markedly different. Now capillary action has a similar effect on concentration as a large increase of superincumbent pressure; and the carbonic acid present in the film of moisture which covers all articles during the rainy season, or in the film separating two surfaces in apparent contact, carbonic acid is in a much more concentrated state than corresponds to the atmospheric pressure. Such carbonic acid is capable of displacing the silicic acid of natural and artificial silicates. Here it is where the mischief comes in. Hence the crusts of sodium and potassium carbonates found plentifully in nallahs of Chota Nagpur and Behar during the dry seasons; hence the dimming of surfaces of glass slides in contact with each other; hence the film which ruins lenses kept in confined situations.

"A chemical change of considerable importance to people having to do electrical testing is the oxidation of the sulphur in ebonite with the consequent formation of sulphuric acid. This change proceeds with considerable rapidity especially during the rainy season. Apparatus which are constantly in use and which therefore are frequently wiped down suffer comparatively little. If, however, the insulation of ebonite parts should be found to have broken down, it is best to moisten them with some dilute caustic potash solution, wash them with plenty of hot distilled water and rub them dry with a clean cloth. Having mentioned ebonite, I am reminded of india-rubber tubing and rubber stoppers. It is astonishing how rapidly they deteriorate in this country The best way of keeping rubber stoppers is to put them into a wide stoppered glass jar at the bottom of which is placed an inverted perforated dish to serve as a support for the stoppers after pouring some oil of turpentine on the bottom of the jar. Stoppers which have acquired a hard cracked surface can be softened by proceeding similarly, only using chloroform instead of turpentine. A good way of preserving rubber tubing is to give it a coating of glycerine. Guttapercha bottles, such as are used for storing hydrofluoric acid, are best protected by covering them all over with paper gummed on.

"I shall not take up your time by dealing in detail with the omnipresent microbe; with the nitre-producing microbe which covers our walls and instrument-pillars with destructive inflorescences. Neither shall I occupy myself with the fever-amœba which causes more havoc and financial loss than many a more quickly acting bacterium; its effect on instruments and machines is only indirect, although sometimes patent enough. More direct is the action of mould. I have often observed beautiful specimens of Mucor growing on ivory parts of apparatus, for instance on ivory pins and eyelets used for insulation. It is chiefly new apparatus which are thus affected, just as it is the new binding of books which suffers most acutely from the attacks of mould. But as only certain constituents of the ivory or the binding of books supply foodstuffs to the growing mould, the latter disappears as soon as those nourishing materials are exhausted. Free circulation of air and plenty

of light are probably the most powerful preventatives of mould-growth."

Having had to refer to dust and dirt, he adds, "I do not think that people out here are always as careful as they might be in protecting their machinery from the deteriorating influence of grit and dust. One sometimes notices even in Europe-bred Europeans a tendency to fall in with the views and habits of the natives. Of course, as regards dust it matters little where a carpenter's bench or a blacksmith's forge is placed; an open shed with a dust-generating mud floor is about as good as anything for ordinary work. But it does make a difference whether first-class machinery, especially dynamo-electric machinery, but also finer lathes and milling machines, are plumped down on a gritty mud-floor or in a cobwebby, dark, damp corner, or whether the machines are placed in a well-lighted machine room provided with a proper brick-on-edge or patent stone floor. It is true a 'pakka' floor costs money; but the ruining of good machinery by grit is not exactly a cheap operation either. There is another superstition alive in the minds of some people, and that is that a dark corner is necessarily a cool corner. This is by no means the case; 85° Fahrenheit in a dark damp room is often less bearable than 95° Fahrenheit in a well-aired, well-lighted room. It is quite true that the Indian coolie is accustomed to dirty surroundings, and although hardly thriving on dust and dirt, the coolie feels quite happy in it. But even he is not accustomed to a life in dark confined rooms. A great part of the Indian's life is really spent in the open air and in sunlight, and he will do his work all the better and the more cheerfully if you give him plenty of air and light in your workshops. Probably the best position in Bengal for an engine and machine room is to have its length in a north-south direction. It should have large venetianed doors in the south and north walls, plain walls on the east and west sides, and in these walls a row of large round or square windows higher up near the ceilings. This arrangement provides a good through-draught and plenty of light."

Mr. Williams.

Mr. C. T. Williams observed that the paraffin wax used in the manufacture of instruments at home appears to be softer than that imported into India for use in the country. This is specially prepared to resist high temperatures. For preventing rust this speaker found that Rangoon oil (the imported, not the local article) was excellent, and that a satisfactory way of storing bright steel parts of instruments in damp climates was to wrap them in paper soaked in Rangoon oil. The Indian Telegraph Department had not hitherto manufactured resistance coils with manganin wire, but this was about to be tried. He was interested in learning that this metal was, in a slight degree, liable to rust, but as the wire would be double silk covered and soaked in paraffin, there would be no reason to apprehend that it would be in any way injured. This speaker drew attention to the very bad work put inside induction coils by some makers at home. It was no uncommon thing to find a coil fail owing to soldered joints being corroded through, this being due to the fact that resin had not been used for a flux. The connection to the condenser was also very faulty. This

Mr. Williams. sometimes consisted of a piece of wire pressing on the tinfoil, and kept in place by a piece of board. The board warped and the connection failed.

Mr. Eustace. Mr. S. EUSTACE said that the conditions prevailing in a hot moist climate were such that it appeared almost impossible to make the mind of an European manufacturer, dwelling in cooler climes, understand. He well remembered at one time writing to a manufacturer and giving him some ideas that would be useful to him in designing machinery for use in India. Instead of gratefully tendering his thanks, he quietly said that as he had been designing machines from the time he (the speaker) was still in petticoats, or a suggestion to that effect, the speaker could not teach him anything. He did not suppose that it was always possible so to design a sensitive instrument, and despatch it, however carefully packed in its working state, that it could be sent by rail in the United States. Manufacturers, however, seemed to think differently, and instead of taking a delicate instrument as much as possible to pieces, and packing the pieces separately, they seemed to consider it sufficient to stuff the moving parts up with silver paper and pack the instruments in straw; and in the latter propensity some seemed to be incorrigible. He admitted, however, that in one direction it was very difficult to preserve instruments properly on the voyage out. The consumers' meters sent out for the Calcutta Electric Supply Corporation, although excellently packed in hermetically sealed cases, as often as not arrived with pinions and gear wheels covered with rust. He would suggest that in a case like this, where the rust must be due to sweating inside the case, that all the cases should be well dried with unslaked lime before receiving their contents, and being sealed up. In the other direction, however, that of mechanical injury due to bad packing, lay one of the chief causes of complaint. The probabilities were that the actual man who did the packing had just about the same amount of conscience as a coolie.

He did not remember any case of a dynamo being burnt out from heat, pure and simple, without some other cause at the back of it. The springs on some of the meters recently imported had been gilded, and this he found fairly satisfactory, though he had had much trouble with ordinary springs previously. He had had cases where a resistance of manganin steel, after withstanding heat for a certain length of time, had disintegrated so that it crumbled in the hand.

There was no question as to what was the fundamental difficulty in preserving instruments and machinery in Calcutta—it was the climate, which had often the same effect on men. Temperature was often a great trouble, and during the hot weather he had known the temperature on the station switchboard to be as high as 112° Fahrenheit, and this with an atmospheric humidity of over 90.

As far as dynamo machinery was concerned, it was advisable to have all the windings well baked before being put into use. He had done this lately with the fan armatures, and the result had been very beneficial.

Mr. Simpson. Mr. M. G. SIMPSON would like to add a word as regards telegraph and telephone instruments. In these instruments it was impracticable

to avoid the use of wood, but all woodwork must be dovetailed or screwed together, and no reliance whatever could be placed on glue. Also the instrument must be so designed that its proper working was quite independent of any warping or shrinking of the wood which might occur. He stated that they had in the Telegraph Department used german-silver wire for their resistances, and found it last very well. They were, however, now experimenting with some of the other materials on the market. Mr. Simpson.

Mr. H. H. REYNOLDS remarked that the condition of cases on receipt depended very largely on the time of the year when they came through the Red Sea. The manufacturers insisted on using straw to a large extent, and in hot weather it invariably rotted and caused damage. He had had a case where a few straws fell and adhered to a greased shaft, and when opened in Calcutta the rust had eaten into the steel. He quoted a case of a large engine packed in England for transit to Calcutta, which was fixed into the packing case by wedges driven in between the cylinder lagging and the case, with the result that considerable damage was done. The speaker believed American packing to be the best, and suggested that this might be due to the extremely rough handling which cases received in America, as pointed out in the paper. He stated that nearly all the ordinary types of instruments rapidly deteriorated when kept in Calcutta; so that after a short time it was not unusual to find inaccuracy amounting to 5, 10, or even 20 per cent. In one case a potentiometer was sent out to him packed in such a way that when opened up it fell to pieces, and yet when it was returned to the manufacturers packed in exactly the same way they complained!

Mr. J. C. SHIELDS was glad to see attention drawn in Professor Brühl's paper to the indifferent way in which instruments sent out from home were sometimes packed. The matter was of great importance in India, and he hoped manufacturers at home would take note of the author's remarks. He remembered on one occasion some delicate instruments being sent out by a firm in Paris. They had been most carefully enclosed in a tin-lined case; but the packing consisted of straw which had not been dried. The instruments were in consequence subjected on the way out to a vapour bath for several weeks, and all the iron parts were a mass of rust. Mr. Shields.

Mr. J. WILLIAMSON remarked that the best way of keeping cases the right side up during transit was to fix battens underneath them, which would lend themselves to the shifting of the case on rollers and which would show better than any label how the case was intended to be placed. In the case o instruments he suggested that it might be possible to avoid damage due to moisture during transit by enclosing a small quantity of calcium chloride in a special cover inside the box, as was done by manufacturers of sensitive photographic papers. Mr. Williamson.

Mr. A. H. POOK said that the Home Institution appointed committees for the purpose of considering all sorts of matter of interest to manufacturers, and he was sure that if they would appoint one on the science of packing for export they would be not only doing the home people a good turn, but would assist users and consumers living abroad Mr. Pook.

Mr. Pook. a great deal in a way which ought in some way to recompense them for our late increase in annual subscription and curtailment of our free literature.

Mr. Meares. Mr. J. W. MEARES said that judging by previous speakers and by the experiences one constantly heard of, the packing question was at the root of the whole matter, and he thought we should take steps to place this most interesting paper and discussion before the home manufacturers, so as to advise them of their shortcomings. Where coolie transit of goods was necessary in the hills, foreign manufacturers would undertake to keep the weight and size of nearly all packages within reasonable limits for the purpose, but the British manufacturer knew better and made not the least effort in this direction, with the result that much damage was sustained. It might be noted that natives of this country had not the remotest notion of shifting heavy packing cases by means of rollers and bars, or of opening the lids by recognised methods. If these points were fully considered something would have been gained in the way of making the packing suitable for the treatment it was likely to receive. Again, it was no uncommon thing for a steel shaft to be packed without any protective grease or paint, and as likely as not the case in which it was enclosed would be extremely damp, so that the fact of soldering it up was not of the least good. As an endeavour to meet the trouble which every one experienced in the rainy season, he had constructed a large drying box in which to keep some of his special instruments during that season, and in a tray at the bottom he was putting calcium chloride to dry the air. The case was made to close on thick felt, so that he hoped it would also entirely prevent the ravages of rats and insects.

Mr. McIntyre. Mr. A. N. MCINTYRE said that he did not know whether any of the members of the Calcutta section had experienced the trouble he had had with the reddish enamel finish given to portable Weston instruments; it became spotted and dull-coloured in patches on exposure. The case was of brass and there was no reason why it should not be lacquered, which though not rendering it proof against climatic influences would at least be preferable to the enamel.

The portable Kelvin-voltmeters supplied us were to all appearances either encased in aluminium or aluminised iron; if it was the latter he could not say much for the process as a corrosion-resisting agent, whatever it might do for iron in contact with salt water. The author of an article in one of the Electrical papers recently referred to an almost perfect solder for aluminium, but unfortunately did not give its composition. While speaking of solders he would ask if the author saw any objection to the use of soft bismuth solder fusing at 320° F. for repairing galvanometer suspensions, since it greatly simplified the task. He had tried it on one of his galvanometers with very fair results, though of course it would not do for resistance coils.

Father Lafont. The Very Rev. Father E. LAFONT (*Chairman*), in closing the discussion, said that most of the remarks which he intended to make on this very interesting paper had been forestalled by other speakers. He had thirty-five years' experience in the care and use of instruments in India, and he suggested that it would be highly desirable that the

Local Section should move the I. E. E. to take up the question of inducing manufacturers to attend to the special needs of India. Father Lafont.

The legs of statical instruments should on no account be fixed on with shellac, and in this point the manfacturers failed to appreciate the difference of climate between Europe and India.

As regards packing, Father Lafont considered that it would be better always to get instruments out in parts and to set them up in India, since the users of electric instruments would generally be competent to do this, or should be so; the makers would then perhaps learn to pack the separate parts so as to be immovable, and he would suggest that they should give their packers a course of lectures on the subject of *inertia*, which they seemed generally to ignore.

As regards rubber tubes and stoppers he enquired if there were any satisfactory method of keeping them. [Professor Brühl here suggested glycerine as a preservative.] He stated that for ebonite, darkness was essential. With reference to a previous speaker's remark he suggested that the decomposition of unpolished ebonite would be greater than that of the polished article, as the rough surface, being less dense and hard, would probably be more easily disintegrated by exposure.

Professor BRÜHL in reply, after referring to the remarks of several speakers, said the chief advantage of using ebonite in an unpolished state, especially in the case of corrugated supporting pillars, was that one could always get a fresh and highly insulating surface by giving it a few touches with fine glass paper. Prof. Brühl.

Some German makers had adopted, for the purposes of articles specially manufactured for tropical countries, what they called a tropical outfit, which he could highly recommend; all metal parts were strongly nickelled, and any Nicol's prisms, which, for instance, might form adjuncts of photometric apparatus, had their calcspar rhombs protected by cover-glasses cemented on with Canada balsam.

It was quite possible that light had something to do with the rapid deterioration of certain kinds of material; but he was under the impression that the influence of light was often exaggerated, especially where, as in Bengal, the sky was commonly covered with a haze, which was almost certain to absorb a considerable percentage of active rays. Several instances of destruction which he had heard described as due to the action of light could almost with certainty be traced to the action of dampness and fungoid growths.

For years he had used a device to keep dry one of his balances as well as a Clifton electrometer. He had replaced the top of the balance case by a shallow box having a perforated bottom, and placed shallow trays containing pieces of fused calcium chloride in the box. The electrometer he had housed in an outer case with a similar top to it. Materials for drying the air should be placed on top; materials for absorbing carbonic acid should be kept at the bottom. As concentrated sulphuric acid began to dissociate at about 30° C. with the formation of volatile sulphuric anhydride, sulphuric acid should not be used in India as a desiccating agent, just as it could not be used for the greater part of the year as an absorbent of water vapour in chemical analysis.

Prof. Brühl.

As regarded dynamos, the chief trouble one had was about insulation. He should advise his friends to specify that armatures and field magnet coils should have every layer of conductors well painted with good shellac varnish or some equally effective composition, and after finishing to have them well baked. If this were done, and if in India the dynamo were properly housed, he did not think there should be much trouble about the insulation breaking down. But there was no good *complaining* about heat and dampness and nitre, and so on. They had plenty of them and to spare; but as practical politicians they must take means to circumvent those injurious agents. If they placed a motor in a pit which was liable to be flooded, they must not blame Providence if the pit did get flooded and the armature burnt out in consequence. If they placed a dynamo in a shed, a couple of inches above a mud-floor and with no possibility of air-circulation, they must not be astonished if the dynamo got ruined by dust, dirt, dampness, and other damaging influences. Damp surroundings produced consumption even in electric machinery.

He did not believe that the life of a good accumulator cell, provided the cell were carefully treated, was much shorter in India than in Europe. But he too had had a fearful experience with a battery. The type of cell was not the kind he had specified, although it was a cell the praises of which had been sung by more than one English authority and in more than one text-book. Luckily the company who manufactured that battery went into liquidation soon after and could do no further harm. But his battery was really a sight worth seeing, after it had been working for six weeks; every positive plate had buckled into the shape of a cocked hat; and one might straighten them, but in a few days there was the cocked hat again. Of course, he had always been very careful about maximum charges and discharges; his battery had been in work practically without interruption, and he had never allowed it to stand without its being charged up at frequent intervals.

He would like to point out to those who had to order instruments the advisability of completely specifying their requirements. After all they must not expect home firms to find out themselves everything about the tropics. When ordering thermometers, he always specified that the capillary tube must end in a small reservoir of a sufficient capacity to receive the overflow mercury up to a temperature of 45° C. He had nearly always found the firms from whom he had obtained instruments ready to receive suggestions and to act on them. Now and then one did come to deal with a firm who thought that they had nothing to learn; but as soon as he found that out, that firm obtained no further orders from him. On the other hand he knew of firms who had made special experiments on wood suitable for tropical climates. There was one firm who had taken a great deal of trouble in trying to evolve a safe system of packing dynamos for shipment to distant countries. Among the worst offenders were the packers of such things as switches, fuses, etc., anything especially that had porcelain parts. It was very easy to pack these articles so that they could be damaged during transit. The principle which should be acted on in packing fragile articles was to fix them rigidly to some rigid support, but to have

Prof. Brühl.

the supporting frame suspended from or supported by springs, the frame being protected from excessive vibrations by layers of fine shavings. He had spoken about the probable influence of the sea voyage. In most cases, however, the mischief was clearly traceable to damp straw or shavings. Straw should be prohibited as a packing material. If possible, one should order one's goods to be sent off from Europe between May and September, or at any rate at a time when there was no slush or soft snow on the ground. He found that the packing cases were filled with what looked like stable litter whenever the case had been despatched during the winter months. In any case he joined with his *confrères* in the expression of the hope that the Parent Society might be moved into seriously taking up the subject of packing for shipment to distant countries.

MANCHESTER LOCAL SECTION.

COMPARISON BETWEEN STEAM- AND ELECTRICALLY-DRIVEN AUXILIARY PLANT IN CENTRAL STATIONS.

By C. D. TAITE, Member, and R. S. DOWNE, Associate Member.

(*Paper read at Meeting of Section on April 7th*, 1903.)

Although the competition for economy in the working of Electrical Generating Stations has now become exceedingly keen, yet the widely different figures obtained annually as the result of the year's working of the many generating stations now in existence lead one to believe that other factors besides the price of fuel and the personnel of the staff affect the figures to a very appreciable extent. The authors are of opinion that the choice of auxiliary plant, for instance, may exercise a strong influence for economy or otherwise, according as the selection has been made, wisely or the reverse; they have therefore endeavoured in this brief paper to put forward some results obtained from plant under normal everyday conditions, in the hope that the figures given, being such as can be obtained from similar plant in any generating station and not the result of full-load tests only, may prove of some practical utility to those who from time to time are called upon to purchase central station auxiliary plant.

That the subject embraces a wide variety of machinery may be seen at once from the following list of auxiliary plant to be found in the majority of stations of fair size, and which are driven by steam engines or electric motors:—

Air Pumps for Condensers.	Economisers.
Cranes.	Coal Elevator.
Feed Pumps.	Ash Conveyor.
Mechanical Stokers.	Workshop.

During recent years it has become the practice to use electric motors almost exclusively for driving the greater number of the above adjuncts of the generating station; for instance, cranes, stokers, economisers, coal elevators, ash conveyors, and workshop are generally now found driven electrically; but condenser air-pumps and also feed-water pumps still adhere to a large extent to steam power; the latter two auxiliaries are running continuously, the running of the others being of an intermittent character. It is, however, becoming increasingly recognised that, quite apart from the power required for driving the plant, the loss from condensation in long ranges of steam piping which are rendered necessary when steam auxiliary plant is used is quite appreciable, and compares badly with the small amount of power

absorbed in the cables of an electrical installation. Another important advantage which electrical methods of driving have over steam power is the ease with which the power taken in the former can be measured, while in the case of steam it is next to impossible to state definitely what is the percentage of power absorbed by the auxiliary plant. In the new generating station of the Salford Corporation, where the whole of the auxiliary plant is driven electrically, it is found that the percentage of power absorbed by the auxiliary plant varies from 8·3 per cent. to 6·5 per cent. of the total power generated, according to the state of the load factor; it is clear that the better the load factor the lower will this percentage be reduced. The following figures are those of an average week taken from the station records:—

TABLE I.

		Percentage of Units Generated.
Units Generated	148,851	
Units used on Works	9,687	6·50
Made up as follows:—		
Condensing Plant	6,962	4·67
Boiler Feed Pumps	1,758	1·18
Mechanical Stokers	555	0·37
Ash Conveyor	110	0·07
Economiser Scrapers (1,600 Pipes)	157	0·11
Coal Elevators	76	0·05
Workshop	65	0·05
Engine-room Crane	4	—

The power taken by the mechanical stokers represented 1·04 units per boiler-hour, which is a rather higher figure than that obtained in many previous weeks, while the economisers required 0·33 unit per hour for driving the scrapers for each battery of 400 pipes; the coal elevators absorbed 0·22 unit per ton of coal raised 40 feet and deposited in the bunkers. The load factor for the week was 39·1 per cent. $\left(\frac{\text{Units generated} \times 100}{\text{Max. load} \times \text{No. of hours in week}}\right)$; as all the power circuits in the works are metred, it will be seen at once how easily one can check the whole of the power taken by the auxiliary plant when that plant is driven electrically; if in any week abnormal figures are obtained, it is a very simple matter to find the cause, as the weekly or even daily returns show clearly on which plant the abnormal consumption is taking place. This fact in itself tends to promote economy, as one soon finds out whether the plant is giving the duty that may fairly be expected from it; a standard of efficiency can thus be set up beyond which the plant must not be allowed to fall.

To turn now from a general comparison to an individual case, it will be generally admitted that there is no more important auxiliary plant in a generating station than the feed pumps; for, unless the pumps are reliable and trustworthy, the supply of steam for the main engine cannot be guaranteed. It is therefore a matter of the utmost importance to make a correct choice of the type of feed pump.

The points which have to be considered are—

1. Reliability.
2. Economy in working.
3. First cost.
4. Upkeep.

Reliability.

Provided that the plant is ordered from experienced firms, there need be no doubt about the reliability of feed pumps, whether they be driven electrically or by steam; both types are equally satisfactory on this score. Those who have any doubt as to the absolute reliability of electric motors have only to consider the case of the tramcar motor, which is working under the most difficult and trying conditions, yet a breakdown of a tramway motor is quite a rare occurrence. How much more reliable, therefore, should a pump motor be which is working under conditions so much more favourable. Nothing more requires to be said to show that, whether the pumps be driven by steam or by electricity, there need be no question as to any want of reliability.

Economy in Working.

Until the advent of the electric motor, steam pump makers appear to have devoted all their attention to making their pumps reliable, and to have left the question of efficiency to look after itself; lately, however, owing to the competition of the motor and to the much improved figures obtained by electric driving, they have been compelled to seriously consider their position, with the result that steam feed pumps can now be obtained which give results immensely superior to those of a few years ago. Still, owing to the nature of the work which they have to perform, steam feed pumps can never compare in efficiency with the main engines installed in the generating station for generating electricity. One well-known firm of pump makers state the steam consumption of their standard 6,000-gallon pump to be as follows:—

Table II.

Gallons delivered.	Lbs. of Steam used per Hour at 160 lbs. pressure.	Lbs. of Water delivered per lb. of Steam used.
1,000	130	77
2,000	253	79
4,000	490	81·5
6,000	714	84

Tests have been carried out at Southport on pumps which have been in use for three or four years, and the following was the average result of several tests each extending over twenty-four hours under ordinary working conditions:—

Lbs. of water delivered per lb. of steam used ... 49·1

The pumps had been recently thoroughly overhauled and fitted with new pump rings; the great discrepancy, therefore, between the figures obtained and those given by the pump makers must be due to the intermittent character of the load, which was at the average rate of 1,460 gallons of water pumped per hour.

At the Salford station tests have been carried out on an electrically-driven 4,000-gallon pump with the following results :—

TABLE III.

	Gallons delivered.	Duration of Test.	Units used.
(1)	8,971	4 hours	27·6
(2)	15,822	4 "	36

If each unit is taken as requiring 30 lbs. of steam to generate it, which is more than 25 per cent. above the full-load consumption of the steam engines installed, the above figures may be stated as follows :—

TABLE IV.

Gallons delivered per Hour.	Lbs. of Water delivered per lb. of Steam used.
2,240	108
3,955	147

Comparing these figures with the figures given above, it will be seen at once how greatly superior the electrically-driven pumps are from the point of duty per lb. of steam than are the steam pumps, and this too in spite of the fact that the full-load overall efficiency of the electrically driven pumps was only 60·67 per cent. The motor in this case was coupled to the pump through worm gearing, which at the time of the test was, comparatively speaking, new, and which is certainly giving better results now. The ratio of the gearing is 12 to 1. It would be interesting if some one could give particulars of tests of pumps electrically driven through spur gearing or by other means.

With regard to the figures obtained at the Southport works, it will be seen that they compare very badly with the electrically-driven plant, and on the basis that the latter absorbs 1·18 per cent. of the total output of the station, the former must be requiring from 2½ per cent to 3½ per cent. of the total output. This is a serious matter, particularly where the price of coal is high, for it is unnecessary to point out that the higher the price paid for fuel the more important does it become to instal economical plant.

The figures given by the pump makers are interesting as showing how slight is the increase in efficiency of a steam pump from light load to full load. The electrically-driven pump, on the other hand, delivers 36 per cent. more water per lb. of steam at full load than it does at half load. This points to the desirability of a careful sub-division of plant where electric motors are adopted.

FIRST COST.

With regard to the money value of the saving in power, this varies directly with the price of fuel, and inversely as the first cost of the plant. In Lancashire, where good slack can usually be obtained for 8s. 6d. to 9s., the money value of the steam saved is less than half what it would be in London and south-country towns, where fuel ranges from 20s. to 30s. a ton.

Still, taking again the Salford figures, 1 per cent. of the present annual coal bill represents £60, and to put the saving in fuel at this station due to the use of electrically-driven pumps instead of steam pumps at £100 per annum is a conservative estimate. Against this saving has to be set the additional interest and sinking fund due to the extra cost of the electrical pumps; say for a 5,000-gallon pump £330, against £125 for a steam pump; allowing 6½ per cent. in each case and the provision of three pumps, the difference per annum would be £40, which reduces the money value of the saving to £60. This may seem a small sum, but it should be remembered that it represents the minimum saving.

Upkeep.

With regard to the question of upkeep there is little if anything to choose between the motor-driven pump and the steam pumps provided that both are well looked after and kept in a proper condition. Care, however, must be taken to see that the delivery range attached to the pumps is provided with a relief valve of ample area to prevent any damage occurring even should the fireman close all his feed valves; otherwise the effect would be to cause a fracture either of the pipes or the pump casing.

The case, therefore, with regard to feed-pumps may be summed up as follows:—

1. *Reliability.*—Both types equally reliable.
2. *Economy in working.*—The electrically-driven pump shows a great superiority.
3. *First cost.*—The electrically-driven pump costs about three times as much as the steam pump.
4. *Upkeep.*—Both types satisfactory.

Generally speaking the authors are in favour of electrically-driven feed pumps, particularly in localities where coal is dear. Where such pumps are used, and in fact where any electrically-driven auxiliary plant is extensively adopted, the authors consider that a battery of accumulators is a practical necessity, as in the event of a total break-down of the generating plant from any cause, the supply of water to the boilers and the lighting of the works would not be interrupted.

Turning now to the consideration of condensing plant, it will be seen from Table I. that the condensing plant at the Salford works absorbs no less than 4·67 per cent. of the total output of the station.

The plant consists of eight sets of jet condensers each provided with an Edwards three-throw air-pump driven electrically through double reduction spur gearing. Each condenser deals with the steam exhausted from a 1,200 H.P. engine, and the water for condensing this steam is drawn from the Manchester, Bolton and Bury Canal. One of the conditions being that the temperature of the discharge water shall not exceed 90° Fahr. it is frequently necessary to use a rather excessive amount of circulating water. The percentage of power taken by the condensing plant when the engine is working fully loaded is 2·4 per cent. This compares with 1½ to 2 per cent. which is the usual allowance when the air-pumps of a jet condenser are driven direct from the

main engine as in mill work; the latter practice is undoubtedly the most economical, as the losses in the dynamo and motor are both saved; but with the modern high-speed engine a direct-coupled condenser is, generally speaking, impracticable, and the choice lies between a separate steam engine and an electric motor. The latter is generally the most convenient to adopt on account of cleanliness and small space required, but the advantage with regard to economy in power rests, if anything, with the steam plant run condensing. Where surface condensers are used the conditions favour the use of electric motors, and the authors recommend their more frequent adoption.

At Southport interesting figures have been obtained in connection with the use of single-phase alternating-current motors driving Gwynne centrifugal pumps for raising water for Korting's ejector condenser. The total lift is 35 feet, the volume of water lifted is 60,000 to 66,000 gallons per hour per engine, and the horse-power of the motors is 35 B.H.P.; the engines to which the condensers are attached are of 1,000 H.P.; during a three hours run the alternator generated an average of 510 units per hour, full load being 600 k.w., and the motor pump took 29·6 units per hour, 5·8 per cent.; the percentage power, however, during the evening's run, averaged as much as 7·26 per cent. of the units generated. As the condensing plant requires a constant supply of water irrespective of the load on the engine, it is evident that when the alternator is generating its full load (600 k.w.), the percentage of power taken by the condenser would be reduced to 4·93 per cent., still a high figure.

A last example of an electrically-driven plant is a motor alternator set at the Salford Corporation Works, used for supplying the outlying districts with alternating current. There are two sets in duplicate, each consisting of a 150 k.w. direct-current motor, direct-coupled to two 120 k.w. alternators; the latter is of an old-fashioned design, having been built in 1894. The two sets are never run together except for the purpose of changing from one to another; one set just takes the full load every night, but during the daytime the load is very light. The average daily efficiency taken over several weeks in the winter amounted to only 72 per cent., the load factor of the plant being 35 per cent.; the maximum full-load efficiency is 84 per cent. This example is given to show the care which must be taken in designing a direct-current supply from an alternating-current generating station when a reasonable efficiency is to be obtained.

A few figures relating to eleven months' working of the auxiliary plant at Salford may be interesting. The total units used during this period by the auxiliaries amount to approximately 410,000, equivalent to 7·0 per cent. of the total units generated; as the cost of fuel is just 0·25d. per unit generated, the money value of the units is £427. There is no doubt that the auxiliary plant is partly responsible for the low coal cost per unit generated, as it has helped to improve the load factor very materially of the generating plant.

Managers of electricity undertakings spend a large proportion of their time in advocating the adoption of electric motors in the interests of the consumer, and with a view of improving the station load factor;

consequently, it is essential that wherever possible they should arrange for electrical driving on their own works.

In conclusion the authors feel that they must apologise for so frequently quoting the figures of the stations with which they are connected; they have been compelled to do so owing to the paucity of other information at their disposal; they trust, however, that their remarks may serve the purpose of eliciting information from other central station engineers with a view of ventilating a subject with regard to which reliable data is not at present easily available.

MANCHESTER LOCAL SECTION.

THE CARRIAGE OF GOODS ON ELECTRIC TRAMWAYS.

By ALFRED H. GIBBINGS, Member.

(*Paper read at Meeting of Section, April 21st*, 1903.)

The many questions involved in the carriage of goods have always been of supreme importance to manufacturing communities in all countries. At the present day when keen international competition is so strong, every improvement in the direction of economy of both time and cost gives an immediate advantage where it is adopted. I need only refer to such a scheme as the Manchester Ship Canal in the illustration of the enormous importance attaching to this subject. But we are not concerned in this paper with the various methods and details of long-distance transit. For long distances both railway and canal carriage are at present essential, and it is true of each that an increased through traffic and lessened local traffic would tend to cheapen existing rates. On the other hand, neither railway nor canal will ever be capable of such extension as to avoid the necessity for the subsidiary use of carts or other vehicles for the collection and distribution of goods, and it is these charges which so largely increase the cost of transportation.

The charges and rates which are at present levied for long-distance transmission may be likened to the reduced charge for electric energy possible only to the long-hour consumer on an electric lighting system. In these cases the "standing charges" rate is reduced in proportion to the length of route or time respectively. A similar analogy exists between the short-distance charges for conveyance of goods by railway, road, or canal, and the short-hour electric light user. Each has to bear a large proportion of the "standing charges" rate. These "standing charges" in the case of goods conveyance consist of heavy interest on rolling stock due to the very low earning capacity on short runs, increased proportion of handling and transhipment costs, station terminal charges, warehousing, etc.

Some of these charges are, of course, bound to occur with any system of handling and transporting goods, and the nature of the goods has also to be taken into consideration, but I propose to show in this paper some of the possibilities of cheapening the cost of conveyance by utilising electric tramway and light railway systems. By the term "short-distance traffic" I refer to conveyance up to fifty miles, but particularly to distances varying from five miles to thirty miles.

Areas of Connected Tramway Systems.

In order to inaugurate and carry on successfully such a scheme, it is necessary to have a considerable area covered by tramways with tracks of uniform gauge. Such an area is illustrated in Fig. 1.

This area includes the following lines, viz.:—

Liverpool Corporation	Gauge 4 ft. 8½ in.
Liverpool and Prescot Light Railway	„ 4 ft. 8½ in.
St. Helens Tramways (Leased by the Corporation to a Company).	„ 4 ft. 8½ in.
South Lancashire Tramways ...	„ 4 ft. 8½ in.
Wigan Corporation...	„ 3 ft. 6 in.
Bolton Corporation	„ 4 ft. 8½ in.
Bolton, Turton and Darwen Light Railways	„ 4 ft. 8½ in.
Darwen Corporation	„ 4 ft.
Blackburn Corporation	„ 4 ft.
Accrington Corporation	„ 4 ft.
Farnworth Urban District... ...	„ 4 ft. 8½ in.
Radcliffe Urban District	„ 4 ft. 8½ in.
Whitefield Urban District... ...	„ 4 ft. 8½ in.
Bury Tramways Company... ...	„ 4 ft. 8½ in.
Rochdale Tramways Company ...	„ 3 ft. 6 in.
Warrington Corporation	„ 4 ft. 8½ in.
Salford Corporation...	„ 4 ft. 8½ in.
Eccles Corporation	„ 4 ft. 8½ in.
Manchester Corporation	„ 4 ft. 8½ in.
Oldham, Ashton and Hyde Tramway Co.	„ 4 ft. 8½ in.
Stalybridge, Hyde, Mossley and Dukinfield Tramways and Electricity Board	„ 4 ft. 8½ in.

Notwithstanding the very complete system described above, it will nevertheless be apparent from the map that much yet remains to be done to reach many of the mill districts, collieries, and outlying townships in order to obviate as far as possible the cost of transhipment, handling, and cartage.

Some considerable attention has already been given to the carriage of goods on electric tramways, the first proposal emanating through the Liverpool Chamber of Commerce in a scheme submitted by Mr. J. T. Wood on October 14, 1896. Mr. Wood says:—

"It is necessary that I should now point out to the Committee that no new departure or principle is involved in the proposal to use tramways for the carriage of goods, nor would it be necessary, in obtaining powers for the proposed tramways, to get any special permission to use them in that manner. . . . The goods and materials for which charges may be made are specified in a minute way, and include, for instance, coal, lime, iron, bricks, castings, sugar, grain,

corn, flour, cotton, wools, fish, etc. A charge is also prescribed for iron boilers, cylinders, and articles of great weight. No objection could, therefore, be raised to the scheme on the ground that it was intended to use the tramway in a way which has not been contemplated by the Legislature; in fact, the general tendency of legislation during the past few years has been in the direction of furthering the trade of the country by the construction of light railway systems."

In referring to this scheme of Mr. Wood's, I must include among the preliminary movements made in the United Kingdom to put into practical effect light railways for goods traffic, that of the inquiry of the Liverpool Chamber of Commerce, whose report, issued on July 22, 1898, embodies no less than twelve proposals for the transportation of goods between Liverpool and Manchester and adjacent centres. The report contains the discussion on each scheme, and a summary of the advantages and disadvantages of each.

In April, 1901, I prepared a detailed report on the subject so far as it applied to the area of the South Lancashire Tramways, and also a special contribution to *Traction and Transmission* in April and May, 1901. During the last two years the following literature has also appeared on the subject:—

"The Conveyance of Goods on Electric Trolley Lines," by A. H. Gibbings; paper read before the Liverpool Engineering Society on January 29, 1902.

"Parcels on Tramways," *Manchester Evening Chronicle*, December 16, 1902.

"Goods Traffic on the Tramways,' *Manchester Guardian*, February 12, 1903.

"Electric Trams and Goods Traffic," *Manchester Guardian*, November 22, 1902.

"Through Traffic on Tramways for Passengers and Goods," paper read before the Liverpool Chamber of Commerce July 21, 1902, by J. E. Waller.

"Running Powers," by A. H. Gibbings; paper contributed to *Traction and Transmission*, April, 1902.

"Some Notes on the Commercial Management of Electrical Tramways," by T. W. Sheffield, *Fielden's Magazine*, January and February, 1903.

"The Commercial Management of Electrical Tramways," by C. H. Wordingham, *The Electrical Review*, January 30, 1903.

"The Conveyance of Goods on Electric Trolley Lines," by A. H. Gibbings, paper read before the British Association, Glasgow, 1901.

The following publications also refer to various methods of dealing with goods traffic:—

"Report of a Special Committee on Light Railways," Incorporated Chamber of Commerce of Liverpool, July 22, 1898.

"Plateways," by Alfred Holt, Liverpool Printing and Stationery Company, Ltd., 42, Castle Street, Liverpool, 1899.

"Heavy Motor Traffic in France," by M. Georges Forestier, The Journal of Commerce Printing Works, 9, Victoria Street, Liverpool, 1900.

"Light Railways," by J. Walwyn White, F.I. Inst. Widnes, 1895; paper read before the Liverpool Chamber of Commerce and the Society of Chemical Industry.

"A New System of Heavy Goods Transport on Common Roads," by Bramah Joseph Diplock; Longmans, Green & Co., 39, Paternoster Row, London, 1902.

"Supplementary Report of the Special Committee on Light Railways," Incorporated Chamber of Commerce of Liverpool, Lee and Nightingale, 15, North John Street, Liverpool, 1900.

"Light Railways and Agriculture," *Electrical Investments Review*, Wednesday, February 4, 1903.

In the foregoing publications many aspects of the question have been put forward and discussed, and to a certain extent, therefore, the rough ground has been broken. Reference to these papers should be made for many interesting features and expressions of individual opinion which it is impossible to embody herein. For instance, in the writer's paper read before the Liverpool Engineering Society in January, 1902, the discussion included remarks by Mr. Brierley H. Collins, M.Inst.E.E., Mr. Alfred Holt, M.I.C.E., Mr. J. E. Lloyd Barnes, Wh. Sc., M.I.Mech.E., and Mr. John A. Brodie, Wh. Sc., M.I.C.E., M.I.Mech.E. (the City Engineer of Liverpool), and others.

Existing Methods and Cost of Conveying Goods.

The usual methods of goods conveyance at the present time are by railways, canals, automobiles, and horse-drawn vehicles. Railway companies have for too long had the sole control of goods traffic. The full use of existing canals, and the possible construction of others, would be a step in the direction of economy.

Some attempt has recently been made under the Locomotion on Highways Act, 1896, to reduce the cost of conveyance of goods between railway and canal depôts and the mills, warehouses, etc., by automobiles, and an excellent paper on that subject was read before the Liverpool Self-Propelled Traffic Association on December 3, 1900, by M. Georges Forestier, who is engineer-in-chief to the Department of Roads and Bridges in France.

The principal method, however, of such local conveyance is by horse-drawn lurries. At the Stalybridge railway goods depôt, for instance, no less than 26 lurries are required to deliver cotton, coal, and other goods to the various mills within the district. At Hyde 42 are required, at Mossley 14, and at Dukinfield 10, and in each of these cases the lurries are owned by the railway companies.

Table I. gives a list of imports and exports into and from Liverpool respectively for the years 1898 and 1899. These figures represent the quantities of goods actually conveyed through Liverpool, exclusive of those which find their way by the Ship Canal direct to the Port of Manchester, the statistics of which are, of course, separately kept by the Custom House authorities as for any other port. I have, however, considered that the Liverpool statistics are in themselves amply sufficient to illustrate the enormous goods traffic in the area described

TABLE I.—TRADE OF LIVERPOOL.

IMPORTS.

Goods.		Year 1898.	Year 1899.
ARTICLES OF FOOD AND DRINK.			
Bacon...	cwt.	2,909,624	2,836,703
Beef	„	1,996,830	2,338,541
Butter...	„	82,504	166,334
Cheese	„	629,386	556,979
Cocoa...	lbs.	3,763,275	9,993,140
Corn and Flour ...	cwt.	44,705,116	49,073,980
Currants	„	457,574	532,938
Eggs	gt. hund.	667,687	606,785
Farinaceous substances	£	279,170	372,265
Fish	cwt.	602,001	627,728
Fruit	£	1,853,684	2,017,264
Hams...	cwt.	1,347,582	1,355,374
Lard	„	909,107	934,166
Milk, condensed ...	„	55,133	56,509
Mutton	„	884,450	848,273
Oil, seed cake ...	„	116,596	134,862
Onions	bush.	1,701,378	2,242,557
Pork	cwt.	393,132	388,142
Potatoes	„	262,444	173,839
Raisins	„	234,901	249,460
Rice	„	1,929,165	2,577,339
Pepper	lbs.	760,228	558,786
Spirits	gall.	1,957,065	1,788,811
Sugar	cwt.	7,510,677	6,559,362
Vegetables, raw ...	£	209,219	211,469
Wine	gall.	2,795,547	2,800,626
METALS.			
Copper	tons	68,300	70,301
Iron	„	87,899	128,091
Lead	„	23,240	24,949
Pyrites	„	178,620	204,243
Quicksilver	lbs.	36,185	6,000
Tin	tons	19,860	27,547
Zinc	„	13,061	10,826
RAW MATERIALS.			
Caoutchouc	cwt.	382,947	336,340
Cotton, raw	„	16,184,362	11,855,495
Hides	„	220,476	297,230
Leather	„	325,837	368,873
Manures	tons	85,677	135,672
Oil, cocoanut & palm,	cwt.	948,119	1,061,606
Paper...	„	241,280	245,945
Paraffin	gall.	188,578	224,036
Petroleum	„	33,565,369	32,490,846
Skins	No.	6,724,212	7,591,634
Tallow	cwt.	621,516	598,643
Tobacco	lbs.	49,284,906	74,307,882
Wood	loads	719,550	797,846
Wool, sheep's ...	lbs.	90,672,043	77,694,198
MISCELLANEOUS.			
Animals, living ...	No.	547,398	533,070
Cork, manufactured	lbs.	2,207,615	2,289,300
Glass manufactures	cwt.	66,041	71,624
Jute ..	£	1,043,215	1,102,999
Rosin	cwt.	373,021	577,811

EXPORTS.

Goods.		Year 1898.	Year 1899.
YARNS AND TEXTILE FABRICS.			
Cotton yarn ...	lbs.	84,967,200	72,738,400
Cotton manufactures	yds.	3,511,282,600	3,640,632,700
Jute yarn	lbs.	7,839,000	7,061,900
„ manufactures	yds.	32,287,800	31,827,500
Linen yarn ...	lbs.	3,472,900	4,239,900
„ manufactures	yds.	80,497,200	102,030,000
Woollen yarn ...	lbs.	1,536,400	1,734,600
Woollen manufactures	yds.	64,284,600	66,814,900
METALS.			
Brass	cwt.	36,331	32,838
Copper	„	253,964	272,066
Iron...	tons	736,533	782,072
Lead	„	2,244	1,959
Tin	cwt.	31,279	33,390
Zinc	„	24,619	20,577
OTHER ARTICLES.			
Alkali	cwt.	3,186,100	3,197,200
Bleaching material	„	879,900	1,049,800
Candles	lbs.	6,792,000	11,253,900
Caoutchouc manufactures	£	250,878	231,791
Carriages, railway	£	910,969	1,019,404
Chemical products	£	1,490,891	1,576,362
Coals	tons	848,218	445,180
Earthenware ...	£	1,093,236	1,231,277
Gunpowder ...	lbs.	3,874,800	2,719,700
Machinery... ...	£	4,584,833	5,080,703
Oilcloth	yds.	5,301,800	5,436,700
Salt	tons	494,458	451,058
Soap	cwt.	684,000	799,000
Spirits, British ...	gal.	451,584	437,809
Sugar	cwt.	615,526	493,671
Tobacco, manufactured	lbs.	1,309,110	1,819,070
Wool, sheep's ...	„	3,808,500	9,706,100
Bacon and Hams	cwt.	89,600	87,523
Caoutchouc, raw...	„	211,113	204,285
Corn and Flour ...	„	1,350,861	1,078,191
Cotton, raw ...	„	849,411	1,646,763
„ waste ...	lbs.	4,716,577	6,839,595
Feathers, ornamental ...	„	126,296	81,035
Fish, cured ...	cwt.	113,919	118,603
Fruit, preserved ...	lbs.	4,773,390	2,783,226
Jute manufactures	£	904,332	1,034,548
Oil, palm	cwt.	569,195	599,366
Quicksilver ...	lbs.	240,590	245,641
Rice...	cwt.	1,097,710	1,631,425
Skins	No.	3,228,065	3,868,753
Spices	lbs.	1,210,934	2,129,892
Sugar	cwt.	280,365	188,848
Tobacco	lbs.	7,007,021	4,535,708
Wool, sheep's ...	„	20,914,920	28,935,732

TABLE II.

Railway Rates from Station to Station for various articles from Liverpool to the undermentioned towns.

Town.	Miles from Liverpool.	Special: S. to S. charge. (s. d.)	Special: Rate per ton per mile. (d.)	1st Class: S. to S. charge. (s. d.)	1st Class: Rate per ton per mile. (s. d.)	2nd Class: S. to S. charge. (s. d.)	2nd Class: Rate per ton per mile. (s. d.)	3rd Class: S. to S. charge. (s. d.)	3rd Class: Rate per ton per mile. (s. d.)	4th Class: S. to S. charge. (s. d.)	4th Class: Rate per ton per mile. (s. d.)	5th Class: S. to S. charge (s. d.)	5th Class: Rate per ton per mile. (s. d.)
Aintree	5	3 1	$7\frac{2}{5}$	3 6	0 $8\frac{2}{5}$	4 4	0 $10\frac{2}{5}$	5 3	1 $0\frac{3}{5}$	7 0	1 $4\frac{4}{5}$	10 6	2 $1\frac{1}{5}$
Ashton	38	7 10	$2\frac{9}{19}$	9 7	0 $3\frac{1}{38}$	11 4	0 $3\frac{11}{19}$	13 1	0 $5\frac{5}{38}$	14 7	0 $4\frac{23}{38}$	21 0	0 $6\frac{12}{19}$
Denton	$37\frac{1}{2}$	7 10	$2\frac{38}{75}$	8 9	0 $2\frac{12}{15}$	10 6	0 $3\frac{9}{25}$	12 3	0 $3\frac{23}{25}$	15 9	0 $5\frac{1}{25}$	21 0	0 $6\frac{54}{75}$
Dukinfield	37	7 10	$2\frac{20}{37}$	9 7	0 $3\frac{4}{37}$	11 4	0 $3\frac{25}{37}$	13 1	0 $4\frac{9}{37}$	16 7	0 $5\frac{14}{37}$	21 0	0 $6\frac{30}{37}$
Earlstown	$14\frac{3}{4}$	4 4	$3\frac{1}{2}$	5 3	0 $4\frac{16}{59}$	6 1	0 $4\frac{56}{59}$	7 0	0 $5\frac{41}{59}$	12 3	0 $9\frac{57}{59}$	14 10	1 $0\frac{4}{59}$
Fazakerley	5	3 8	$8\frac{4}{5}$	5 3	1 $0\frac{3}{5}$	6 1	1 $2\frac{3}{5}$	7 0	1 $4\frac{4}{5}$	8 9	1 9	15 9	3 $1\frac{4}{5}$
Garston	$5\frac{1}{2}$	4 4	$9\frac{5}{11}$	4 9	0 $10\frac{4}{11}$	5 3	0 $11\frac{5}{11}$	6 1	1 $1\frac{3}{11}$	10 6	1 $10\frac{10}{11}$	13 1	2 $4\frac{6}{11}$
Glazebrook... ...	$24\frac{1}{2}$	7 0	$3\frac{21}{49}$	7 10	0 $3\frac{41}{49}$	8 9	0 $4\frac{2}{7}$	9 7	0 $4\frac{34}{49}$	12 3	0 6	15 9	0 $7\frac{5}{7}$
Gorton	34	7 4	$2\frac{10}{17}$	8 3	0 $2\frac{31}{34}$	9 7	0 $3\frac{13}{34}$	11 4	0 4	14 10	0 $5\frac{4}{17}$	18 4	0 $6\frac{8}{17}$
Guide Bridge ...	36	7 10	$2\frac{11}{18}$	9 7	0 $3\frac{7}{36}$	11 4	0 $3\frac{7}{9}$	13 1	0 $4\frac{13}{36}$	16 7	0 $5\frac{19}{36}$	21 0	0 7
Heywood	$38\frac{1}{4}$	9 7	3	11 4	0 $3\frac{85}{153}$	13 1	0 $4\frac{16}{153}$	15 9	0 $4\frac{144}{153}$	19 3	0 $6\frac{2}{51}$	23 7	0 $7\frac{61}{153}$
Hollinwood ...	36	9 11	$3\frac{11}{36}$	11 4	0 $3\frac{7}{9}$	13 1	0 $4\frac{13}{36}$	14 10	0 $4\frac{17}{18}$	18 4	0 $6\frac{1}{9}$	23 7	0 $7\frac{31}{36}$
Hyde	$38\frac{1}{2}$	7 10	$2\frac{34}{77}$	9 7	0 $2\frac{76}{77}$	11 4	0 $3\frac{41}{77}$	13 1	0 $4\frac{6}{77}$	16 7	0 $5\frac{13}{77}$	21 0	0 $6\frac{6}{11}$
Kenyon Junction ...	$18\frac{3}{4}$	5 3	$3\frac{9}{25}$	6 1	0 $3\frac{67}{75}$	7 0	0 $4\frac{36}{75}$	8 9	0 $5\frac{9}{15}$	13 1	0 $8\frac{28}{75}$	16 7	0 $10\frac{46}{75}$
Leigh and Bedford	$21\frac{3}{4}$	5 3	$2\frac{26}{29}$	6 1	0 $3\frac{31}{87}$	7 0	0 $3\frac{25}{29}$	8 9	0 $4\frac{24}{29}$	13 1	0 $7\frac{19}{87}$	15 9	0 $8\frac{20}{29}$
Manchester ...	$31\frac{1}{2}$	7 4	$2\frac{50}{63}$	8 3	0 $3\frac{1}{7}$	9 7	0 $3\frac{41}{63}$	11 4	0 $4\frac{20}{63}$	14 10	0 $5\frac{41}{63}$	18 4	0 $6\frac{62}{63}$
Mossley	42	8 9	$2\frac{1}{2}$	10 6	0 3	12 3	0 $3\frac{1}{2}$	14 0	0 4	17 6	0 5	21 10	0 $6\frac{5}{21}$
Oldham	37	8 9	$2\frac{31}{37}$	10 6	0 $3\frac{15}{37}$	12 3	0 $3\frac{36}{37}$	14 10	0 $4\frac{30}{37}$	18 4	0 $5\frac{35}{37}$	23 7	0 $7\frac{24}{37}$
Prescot	$7\frac{3}{4}$	4 4	$6\frac{22}{31}$	4 9	0 $7\frac{11}{31}$	6 1	0 $9\frac{13}{31}$	7 0	0 $10\frac{26}{31}$	8 9	1 $1\frac{17}{31}$	12 3	1 $6\frac{30}{31}$
Royton	$40\frac{1}{2}$	9 7	$2\frac{68}{81}$	12 3	0 $3\frac{17}{27}$	14 0	0 $4\frac{4}{27}$	17 6	0 $5\frac{5}{27}$	21 0	0 $6\frac{2}{9}$	23 7	0 $6\frac{80}{81}$
Staleybridge ...	$39\frac{1}{2}$	7 10	$2\frac{30}{79}$	9 7	0 $2\frac{72}{79}$	11 4	0 $3\frac{35}{79}$	13 1	0 $3\frac{77}{79}$	16 7	0 $5\frac{3}{79}$	21 0	0 $6\frac{30}{79}$
Warrington ...	18	4 4	$2\frac{8}{9}$	5 3	0 $3\frac{1}{2}$	6 1	0 $4\frac{1}{18}$	7 10	0 $5\frac{2}{9}$	9 7	0 $6\frac{7}{18}$	13 1	0 $8\frac{13}{18}$
Wigan	19	6 3	$3\frac{18}{19}$	7 0	0 $4\frac{8}{19}$	7 10	0 $4\frac{18}{19}$	10 6	0 $6\frac{12}{19}$	13 1	0 $8\frac{5}{19}$	16 7	0 $10\frac{9}{19}$

although there can be no doubt that a very large distribution occurs at Manchester, both within its own area and those of the districts contiguous.

These figures, of course, take no account whatever, nor give any indication, of the immense local goods traffic within each district or between several districts. It is very difficult to obtain any adequate idea, and still more detailed statistics, of purely local requirements, in this direction, except such as can be gained by direct association with any particular locality. It may, however, be taken as being very considerable.

It will be apparent from these remarks that an enormous number of lurries must be employed to convey goods from the docks to the railway termini. In Liverpool the number of horses used solely for this purpose is about five thousand, and the distance from dock to railway averages about two miles. When the goods arrive on the lurry at the railway terminus it is not always convenient, even there, to tranship directly into the railway truck, and in that case the goods have to be deposited for the time in the shed. Thus two, and sometimes three, handlings are involved before the goods are moved an inch by the railway company, and this condition of affairs gives rise to "service terminal charges." Somewhat similar processes have to be again gone through when the goods arrive at the end of their transit by rail, causing repeated expense and delay before they are actually on the road to the user or consignee. The expense consequent on these complications is naturally heavy in any case, but exceptionally so in regard to conveyance over comparatively short distances. The cartage rates alone* (after payment of dock dues, master porterage, quay accommodation, etc.), between docks and railway termini, may be taken at 1s. 3d. per ton as a representative average for all classes of goods not exceeding two tons in weight for any single piece or article. The station and service terminal charges vary from sixpence to seven shillings per ton from coal to high-class goods according to the grade, and these charges have to be added on to the total cost of conveyance. In Table II. a list is given of railway rates (exclusive of station terminal charges) from Liverpool to various towns within, or adjacent to, the area shown in Fig. 1.

In addition to the economies which will be effected with the electric trolley system, through the reduction in the cost of handling, the avoidance of heavy station terminal charges and other tolls, and the disappearance of carter's charges at least at one end of route, further savings may be anticipated through the higher average weight which it will be possible to deal with per car per mile, and the small capital involved when compared with railway rolling-stock and adjuncts.

The average load of a railway merchandise truck does not exceed three tons. (This statement was given in evidence by Sir George Finlay.)

It may, *per contra*, be very reasonably assumed that with the extra

* For further particulars see Report of Dock Rates Sub-Committee, 1895, and Report of Manchester Ship Canal Special Committee (1894) of Liverpool Chamber of Commerce.

staff required, when no more than two trucks are marshalled together the standing charges will be relatively higher than that of railway companies. But this is only one item in the case after all. As against this we must remember that no expensive and time-absorbing shunting operations are necessary, that no signalling is required, and that each truck will have at least four times the earning capacity of the railway truck, owing to the much more rapid transit and delivery of goods. Careful calculations have been made, and it is found possible to charge, for full loads, only 50 per cent. of the present railway charges, and then leave a sufficient commercial profit. Reference to Table II. will show the present prices under the various classes. Take the instance given on page 1063. The total cost works out to 4⅓d. per ton per mile. If conveyed by electric traction this cost would not exceed 2d. per ton per mile, irrespective, that is in both cases, of the cost of conveyance from the depôt. The saving in time of transit is also very important.

Let us assume the destination is Bolton. By road through Knotty Ash, St. Helens, Abram, Hindley to Bolton the distance is about twenty-nine miles. After allowing for all stoppages an average speed of six miles an hour may be anticipated, and the entire journey would therefore be accomplished in 4⅚ hours. Compare this with existing methods. First of all lurry loads to the railway terminus, then handling of goods a second time in transferring to railway waggons; thence a railway journey involving the marshalling of trucks, shunting, coupling and uncoupling, and after perhaps eighteen hours, arrival at Bolton. Here again there is handling a third time in transferring to lurry, and possibly service terminal charges to pay.

The time which these operations and the entire journey would involve might be calculated to be about twenty-four hours.

As a matter of fact, the basis of calculation and items of cost will average very little different from that for passenger traffic, and the foregoing figures have been arrived at on an assumed revenue of 12 pence per truck-mile. It will be seen that for full loads of ten tons at, say, 2d. per ton, the revenue would be 20 pence.

Proposed Methods of Handling and Transportation.

An ideal scheme for the conveyance of goods from any one part to any other part of such an area as exists in South Lancashire should comply with the following conditions:—

1. The goods should be loaded direct from the docks, warehouses, or depôts, and deposited, without further handling, at their ultimate destination.
2. In order to carry out the above condition, special sidings should be run in to warehouses, mills, etc.
3. There should be no special stoppages or delay in transit from the loading point to the destination.
4. The service, when necessary, should be continuous for the whole twenty-four hours per day, excluding, perhaps, Saturdays, Sundays, and public holidays; but even on these days a service should be available if urgently required.

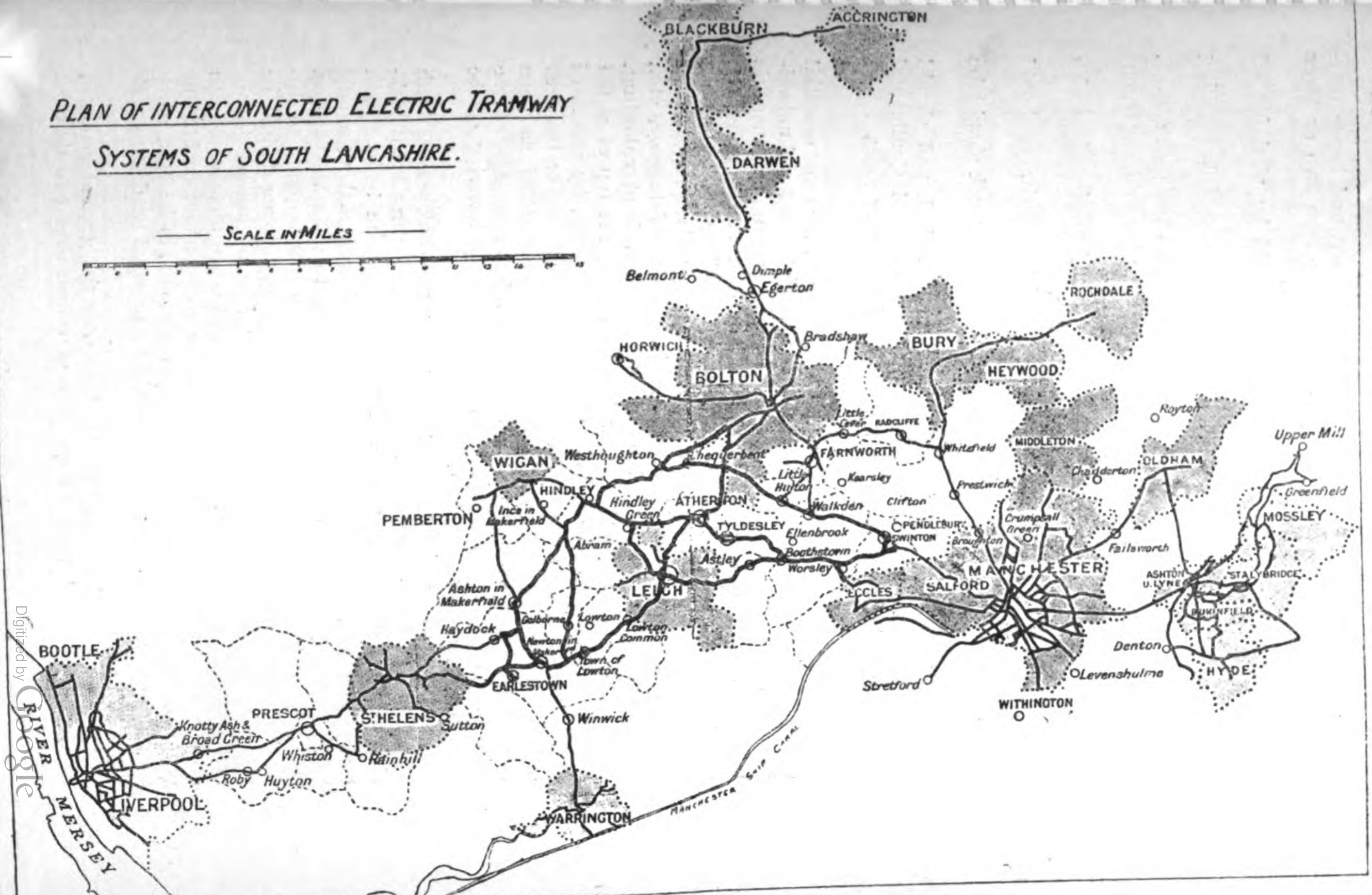

PLAN OF INTERCONNECTED ELECTRIC TRAMWAY
SYSTEMS OF SOUTH LANCASHIRE.
SCALE IN MILES
BLACKBURN
ACCRINGTON
DARWEN
Belmont
Dimple
Egerton
Bradshaw
HORWICH
BOLTON
BURY
HEYWOOD
ROCHDALE
Little Lever
RADCLIFFE
FARNWORTH
Whitefield
MIDDLETON
Royton
OLDHAM
Upper Mill
Greenfield
MOSSLEY
WIGAN
Westhoughton
Chequerbent
HINDLEY
Hindley Green
ATHERTON
Little Hulton
Kearsley
Prestwich
Chadderton
PEMBERTON
Ince in Makerfield
TYLDESLEY
Walkden
Clifton
PENDLEBURY
Crumpsall Green
Broughton
SWINTON
Ellenbrook
Boothstown
Worsley
Astley
Abram
Failsworth
MANCHESTER
SALFORD
ECCLES
ASHTON U. LYNE
STALYBRIDGE
DUKINFIELD
Ashton in Makerfield
LEIGH
Golborne
Lowton
Lowton Common
Haydock
Town of Lowton
EARLESTOWN
Denton
HYDE
Levenshulme
Stretford
WITHINGTON
BOOTLE
PRESCOT
ST HELENS
Sutton
Winwick
Knotty Ash & Broad Green
Whiston
Rainhill
Roby
Huyton
LIVERPOOL
WARRINGTON
RIVER MERSEY
MANCHESTER SHIP CANAL

FIG. I.

5. No shunting operations should be necessary, and hence marshalling should be avoided. Not more than two or three trucks should be marshalled together.
6. One or two special forms of trucks should be used for all classes of goods.
7. The service should be expeditious, but not necessarily entailing a high rate of speed.
8. The system should possess every facility for the transference of goods (without handling in piece) to or from railway trucks or horse lurries.
9. The line for the conveyance of goods should not interfere with any passenger or ordinary road traffic.
10. No alteration in the existing gradients of the roadways should be necessary.
11. The maximum weight to be carried on each truck should be not less than nine tons.
12. The charges should be reasonably economical, and should compare more favourably with American and Continental railway rates than the present British railway rates.

In the foregoing list it will be noticed that one of the most essential conditions to ensure economy is the avoidance of loading and unloading between terminals. In other words, wherever transhipment is necessary, the goods should be handled in bulk and not in part. Some attempt has already been made in that direction by certain railway companies. The South Eastern Railway Company have a special arrangement for conveying goods, passengers' luggage, etc., from London to various parts of the Continent without unloading. It consists of a detachable van which rests upon the top of a flat railway truck. This van is provided with steel ropes, by means of which it is lifted by a crane from the truck and deposited on the deck of the steamboat, or *vice versâ*. Fig. 2 shows the van after it has been lifted from the railway truck, and also the relative position of the steamboat, crane, and railway. Fig. 3 illustrates the lowering of the van on to the steamboat deck.

For the purpose of facilitating the transport of coal, several South Lancashire collieries use coal waggons constructed with three detachable sections or boxes, in place of the usual waggon body. Each section carries on an average 2½ to 3 tons of coal, making a total carrying capacity of the sectional waggon 7½ to 9 tons, as against 9 to 10 tons of the ordinary coal truck. When it is required to discharge these trucks it is only necessary to lift any section desired by means of lifting rings provided, and empty through a bottom door or in the usual tip method adopted, with a third chain attached to one end for the purpose of tipping. The above arrangement enables the coal-handling machinery at any coal terminus, etc., to be of a much simpler and lighter character than would be required for dealing with the whole truck.

On the Donegal Railway Mr. R. H. Livesey, the general manager, has had to contend with the question of transit over two different

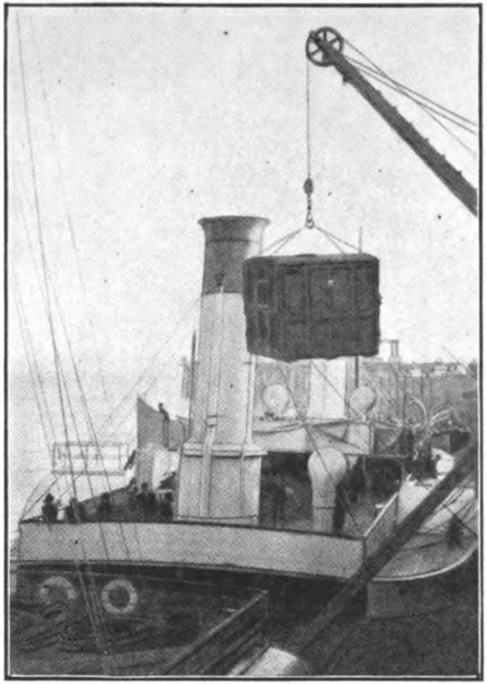


FIG. 3

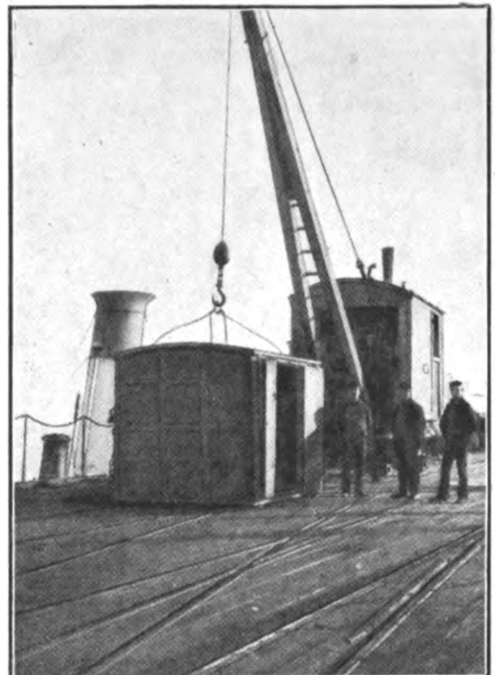


FIG. 2.

gauges, viz., 5 ft. 3 in., which is the standard gauge of Ireland, and 3 ft., which is the gauge of the Donegal Railway. Figs. 4 to 7 illustrate the arrangement, and I cannot do better than describe the operation in Mr. Livesey's own words. He says :—"No lifting arrangements are required, as the bodies are taken over by means of rollers, which run on rails secured to the under-frames. The size of the bodies are the same as used by the broad gauge in this country —*i.e.*, 5 ft. 3 in.—and they are 15 ft. 6 in. long by 7 ft. wide. We carry any description or class of goods in them. The system was only brought into use about four years ago, and since then it has been such a success that we have decided to gradually alter the whole of our goods, etc., waggons to it, as it has done away with delays due to transhipments and loss through breakage, besides effecting a great saving in cost of handling, as two men can do all that is required in a few seconds.'

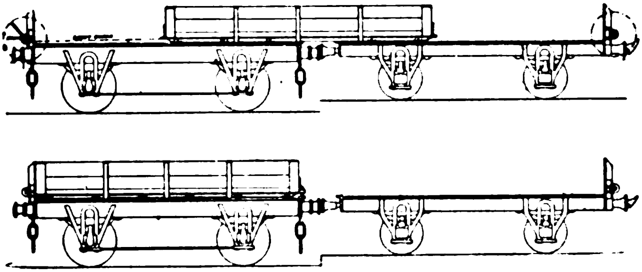


Fig. 4.

A somewhat similar arrangement is that of Cowan's patent truck, illustrated in Fig. 8. The object is the same in both cases, viz., to tranship goods in bulk without unloading.

From the information and illustrations which have just been given it is not difficult to suggest a system of dealing with goods on electric trolley lines or electric tramways which should prove adequate for all purposes, and which shall comply with the greater number of the conditions already set forth. I propose two forms of goods trucks, one on the lines of the Pittsburgh Express Car, Fig. 9, for conveying miscellaneous goods and for local traffic, but modified to meet conditions of English practice as shown in Fig. 10; the other to be an application of the principle adopted by the South Eastern Railway and the Lancashire Colliery Railways to which I have already referred, viz., detachable tops on plain trucks, provided with facilities for removal by means of cranes. This arrangement is indicated in Fig. 11, and should answer for the majority of cases. The comparative sizes of this car and the ordinary railway truck and road lurry are as follows :—

Electric trolley truck ...	22 ft. 0 in. × 6 ft. 6 in.
Railway truck	16 ft. 0 in. × 7 ft. 10 in.
Road lurry (two-horse) ...	17 ft. 6 in. × 7 ft. 3 in.

The train in this case would consist of one motor truck and one trailer, carrying together from 18 tons to 20 tons. The motor trucks would be of the double bogie type, with an extension at each end for the motor man and controlling gear.

Magnetic track brakes would have to be provided, in addition to electric and wheel brakes, for use on heavy gradients and for emergency. The trucks would also be provided with wooden or iron bars for supports for tarpaulin covers, when required.

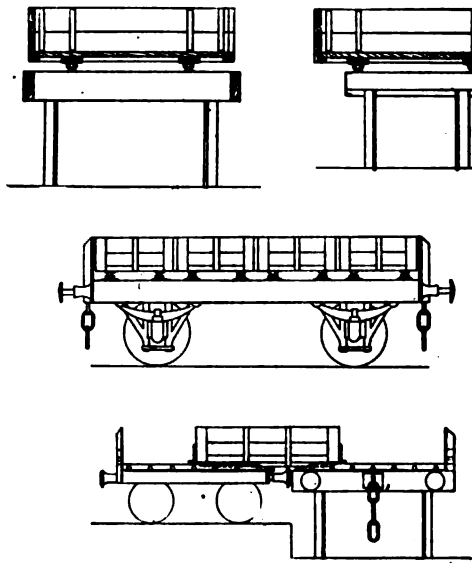


FIG. 5.

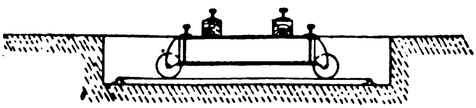
In the United States the conveyance of goods on electric trolley lines has been very considerably developed. The Pittsburg Express Company, Pittsburg, Pa., had, in 1900, in operation ten cars of the type shown in Fig. 9.* Each car will carry 8 tons, the length of the car being 29 ft. 10 in. overall. The Company in 1900 was making an average of sixteen round trips per day, with a total daily mileage of 270 car-miles, or 7,020 car-miles per month. It handles both express packages and heavy freight of all kinds. On level and through runs, when there is not too much local street delivery, express trailers can be

* See also *Street Railway Journal*, December issue, 1900, page 1,148. For further reference to freight and express conveyance see also the following issues of the *Street Railway Journal* :—June issue, 1897, Newburgh Street Railway Company, page 348; September issue, 1898, Buffalo and Lockport Railway Company, page 535; June issue, 1899, Mail Car, page 353; August issue, 1900, Funeral Cars, page 382; December issue, 1900, Funeral Cars page 703.

operated satisfactorily, even during the busy part of the street-car day, and for night runs their use is a great aid in reducing the cost of transport.

Some considerable development of goods traffic on electric trolley lines has taken place in Detroit, Michigan, notwithstanding a bye-law which prohibits the use of trailers, and which levies a tax of one dollar per car per round trip, regardless of whether the car is empty or loaded.

The illustrations Figs. 12 to 17 give a fair idea of the traffic handled. The main depôt is 45 ft. by 195 ft. On one side is the team track or driveway, where freight is received and delivered. On the east side of the shed there are double tracks with accommodation for four cars on



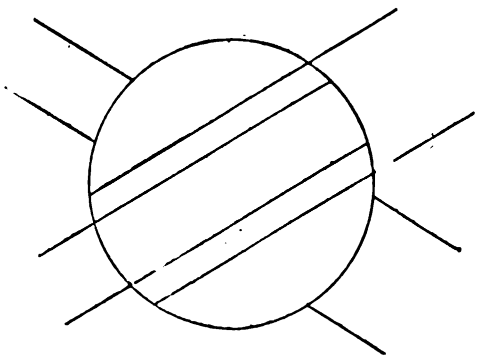


Fig. 6.

each track, with ample room for switching. The interior of the shed is clear of all posts, thus giving ample floor space necessary for prompt receiving and loading the freight. There is also cold storage for the protection of perishable goods during the summer months.

The carriage of goods in Detroit had its origin in the transportation of milk, which was originally handled in a small compartment on passenger cars reserved for baggage, but which has now grown to such proportions as to tax daily the capacity of entire special cars. The rate on the different commodities handled is according to the value, dimensions, and weight of each article. For example, shipments of glassware, furniture or suchlike are rated much higher than milk or hardware.

On the Continent we have to turn to Belgium—the land of agricultural produce—for any extensive system of light railways for goods traffic.* Most of these, however, are steam railways, and differ but slightly in their methods and operation from the ordinary main railroads of the country. As a matter of fact they act principally as affluents or feeders to the larger railways.

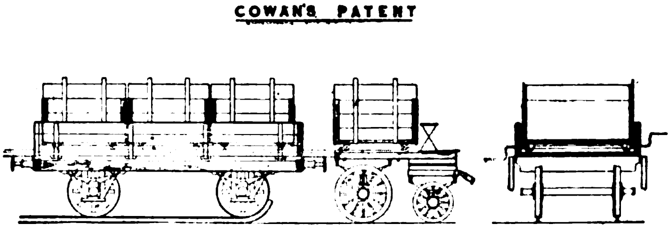


FIG. 8.

There is in Germany a freight line constructed by the Union Electricitäts Gesellschaft at Aachen (Aix-la-Chapelle) six years ago, which runs ordinary motor trucks, having, however, no special detachable body.

When the writer was visiting the Düsseldorf Exhibition in 1902, he saw a very interesting system of general goods and milk conveyance on electric tram lines. The line is really a light railway owned by the

* A correspondent in Brussels sends the following remarks :—"Since the 1880 Belgian law, ruling the working of light railways, more than 2,000 kilometres of 'Vicinal' tramways have been constructed (one metre gauge, with the exception of two lines), and they are all reported to be in a prosperous state. This latter point, although being rather difficult to ascertain (as the working of the lines have all been leased to private concerns), may be considered as correct, because the Société Nationale des chemins de fer Vicinaux, proprietors of all lines, consider the present result as satisfactory. All these tramways, with a few exceptions, are steam tramways, and there is a vague question of replacing steam by electricity ; they are destined for the conveyance of goods, passengers and luggage. Light railways are here mostly affluents of transport to large railways, especially the farm and greenhouse products, such as beetroots, fruits, vegetables, milk, eggs and butter, also cattle and all market produce, for large centres such as Brussels, Ghent, Antwerp, Liège, etc. As regards mineral traffic, Belgium being small, and the system of the State railways very much developed indeed, collieries avail themselves of private sidings. The charges, freight, etc., are fixed by the Belgian State, through the Société Nationale des chemins de fer Vicinaux, and are determined according to the local necessities. As regards the revenues, they vary with local conditions, and the Société Nationale themselves fix the probable revenues the lines are to bring. As an average they allow from 1,700 francs to 3,000 francs per kilometre per annum to the concern working, under lease, the line ; dividing the surplus with the latter in proportion to 30 per cent.-50 per cent. (for benefit, maintenance of the line, etc.), when their estimate has been confirmed by the receipts. Should the receipts not amount to the fixed allowance, the difference is borne by the Société Nationale. It is reported that, as a rule, the Société Nationale share the surplus after two to four years' working. About thirty private concerns find a remunerative business in working, under lease, the 'Vicinal' lines."

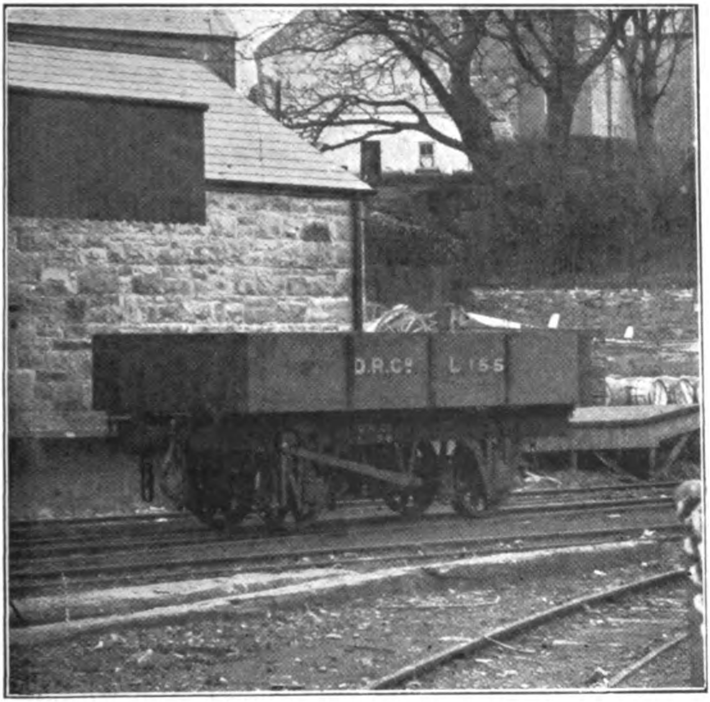


FIG. 7.

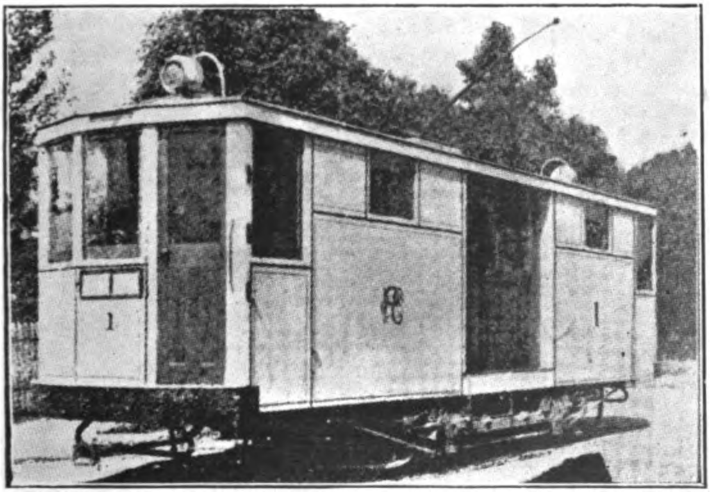


FIG. 9.

Rheinische Bahn-Gesellschaft, and carries passengers and goods. Unfortunately, no illustrations are available. The articles carried are piece-goods, milk and agricultural produce. The line is 22 kilometres in length, and connects the two towns of Düsseldorf and Krefeld, having an aggregate population of 350,000. The intervening country is principally agricultural, and there is a very considerable milk traffic from the intermediate stations to Düsseldorf. For the carriage of piece-goods the almost universally current rate (in Germany) of 20 pfennige per ton per kilometre is charged (equal to about $3\frac{1}{4}$d. per ton per mile).

The carriage on milk is on the following basis: For a distance of 10 kilometres a minimum rate of 30 pfennige per 100 kilos. (equal to $1\frac{1}{2}$d. per cwt.), and for every further five kilometres, 5 pfennige extra (about 3 miles—$\frac{1}{4}$d. extra).

Carriage is charged on, (*a*) the weight of the milk carried, including the weight of the cans; (*b*) half the weight of the returned empty cans. Fractions of 10 kilos. are charged as 10 kilos. full.

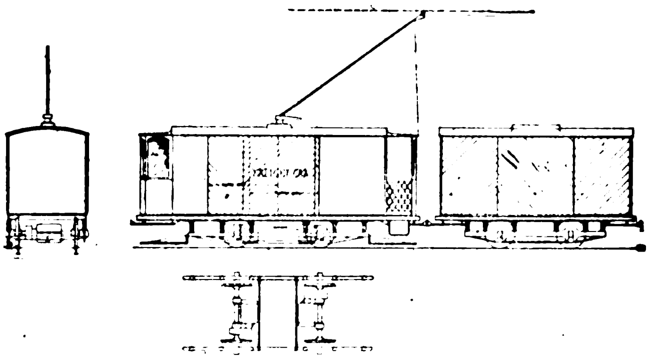


FIG. 10.

Milk is received and forwarded principally in the early hours of the morning to 7.30 a.m. An opportunity is, however, afforded to forward the milk also at noon and in the evening. Piece-goods are forwarded three times a day, viz., morning, noon, and evening, by permanently appointed passenger trains.

Goods are conveyed in 4-axled covered wagons of $8 \times 2 = 16$ square metres (175 square feet) floor space, having a tonnage of 10 tons.

A complete translation of the conditions for forwarding milk, etc. together with the tariff charged will be found in the Appendix.

In Switzerland there is a line between Burgdorf-Thun, which is built for passenger service, using ordinary motor trucks, and electric locomotives with freight trucks (without motors) for the freight service.

To revert to the United Kingdom, one finds very little that has been done in this direction even from a prospective standpoint. The Light

Railway Act of 1896 has been almost entirely inoperative. When the opportunity for carrying goods has arisen, such as in South Lancashire, in the Potteries district, on the Middlesbrough and Stockton lines and elsewhere, many difficulties have been placed in the way by the action of property owners and local authorities. This aspect I will deal with in the next section.

The South Lancashire Tramways Company have now appointed a goods traffic manager who will deal with the area in which they are interested. The Huddersfield Town Council have contracted with Messrs. Martin, Sons & Co. to convey coal for seven years over the tramways from a railway siding. The company requires from 45 to 50 tons of coal per day. Specially constructed waggons will be used; they will hold about 5 tons of coal each, and each will be driven by two electric motors. There is a short line from Welshpool to Llanfair for the conveyance of both goods and passengers. A company called the Tramways Parcel Express Syndicate, of Bradford, Yorks, exists for the collection and delivery of parcels, and it is open to make arrangements in connection with tramway undertakings for the conveyance of parcels

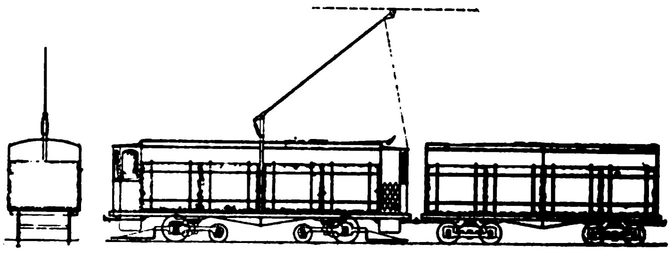


FIG. 11.

at a mileage rate. The company provides its own crates and receptacles for parcels, and places them on and removes them from the cars, so that no delay or expense attaches to the tramway authorities. Special facilities would of course have to be provided for accommodating the crates, etc.

Messrs. Twinberrow and Sheffield, of Newcastle-on-Tyne, have designed several special types of goods waggons, both motor and trailer, suitable for running on tramway lines, for conveying coal, bricks, pig iron and general merchandise.

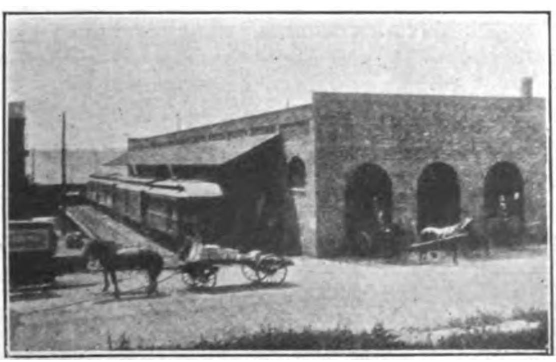
Direct and Indirect Advantages.

The principal advantage resulting from the development of goods traffic on tramways will, of course, accrue to the company or authority owning the tramways or over whose system the goods are conveyed.

Parliament has already granted the powers to convey such goods and although additional capital is required to provide the necessary

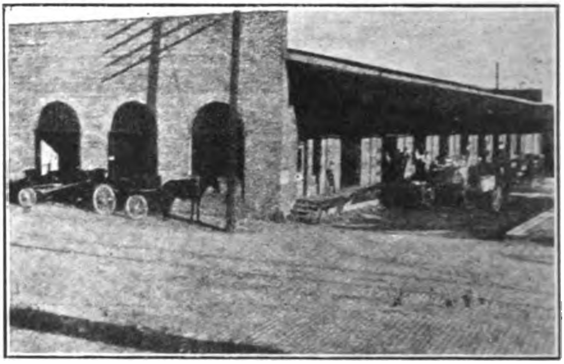
Interior View of Milk Car.

Interior View of Electric Depot at Detroit.



Tracks for Cars on East Side of Electric Depot at Detroit.

Interior View of Express Car.



Team Track Delivery on West Side of Electric Depot, Detroit.

Express Office and Milk Platform at Clawson, Mich.

rolling stock and equipment, the earning capacity of the permanent way can by this means be very largely augmented. The cost of the permanent way is, in the majority of cases, the more expensive portion of the system, costing from £7,000 to £10,000 per mile.

The advantages to the manufacturer, colliery owner, and warehouseman are quick delivery and low freight charges.

The advantages to local authorities generally are more than are immediately apparent. For instance, in any manufacturing community where there are cheap freight rates combined with other local facilities, there the manufacturer will settle. Not only will the rateable value be increased, but the present rates will in all probability decrease. The profits accruing from municipally-owned electric traction undertakings are often applied to the relief of the rates, and in those cases where independent companies own and work them the roadways are not only greatly improved for general traffic but are also kept in repair. The principal public benefit in this connection, however, will consist in the great relief of the streets from lorry traffic. The cost of road maintenance from this cause alone is very great. The surveyor to the Tyldsley Urban District Council finds that the cost of road maintenance for four years averages £233 2s. per mile per annum, exclusive of scavenging. In Bolton the annual expenditure on main roads varies from £7,000 to £10,000, and on other roads about an equal amount. The surveyor is of opinion that if goods were carried on the tramways a considerable saving would be effected, and if this is the experience in these towns it may safely be assumed to be the case also in Liverpool, Manchester, etc.

In a paper read before the annual meeting of the Incorporated Association of Municipal and County Engineers, at Leicester, by Mr. W. Worby Beaumont, entitled "The Wear of Roads by Horse Haulage and Motor Traffic," the author remarks: "Since the days when Telford and MacNeill, his resident engineer (afterwards Sir John MacNeill), and others gave so much attention to the subject, it has been recognised that the wear of roads by horses' shoes was considerably greater than the wear of roads by the wheels the horses hauled. It was shown by the observations of MacNeill that the wear by the horses hauling heavy vehicles and heavy loads was less than that by the horses hauling the lighter loads at the higher speeds. The relative proportions of the wear under these different classes of traffic were fully stated in evidence before the select committee on steam carriages in 1831, and very little has transpired since to alter the qualitative value of the conclusions then announced, although road and vehicle improvements have added to the number of exceptions to their quantitative value." (See Report of Select Committee in Gordon's "Elemental Locomotion," page 131, *et seq.*) The causes of road wear were summarised for a general statement, and may be collated as shown in the following table:—

General Results of Observations of Causes of Road Wear and Deterioration.

Kind of Vehicle and Load.	Wear due to atmospheric causes.	Wear due to wheels.	Wear due to horses' feet.
London and Birmingham Coaches: Weight, 16 cwt. to 18 cwt. empty; loaded, 45 cwt.; speed, 8 to 12 miles per hour	20 per cent.	20 per cent.	60 per cent.
Wagons: Weight, 25 cwt.; loaded, 92 cwt.; speed, 3 miles per hour	20 "	35·5 "	44·5 "

Another of the indirect advantages will be the decreased cost of generation at the power-stations. It is well known that an increase in the output of a generating works, without a corresponding increase in the maximum demand or staff, results in a much lower average cost per kilowatt-hour or Board of Trade unit. In Table III. a graduated scale of costs is given for varying load-factors, from which the principle just

TABLE III.

Cost of generating electrical energy with varying load factor in pence per kilowatt-hour at dynamo terminals, maximum demand—2,000 K.W.

Items of Cost.	Electric Lighting. 10% load factor.	Combined Electric Lighting and Traction. 20% load factor.	Electric Traction, Passengers only. 40% load factor.	Electric Traction, Passengers and Goods 60% load factor.
	Pence	Pence	Pence	Pence
1. Coal at 12/- per ton, Oil Waste, Water and Stores	·53d.	·41d.	·38d.	·35d.
2. Wages of Engine Room and Boiler Room, Staff, &c., superintendence at 8 hour shifts ...	·30d.	·20d.	·12d.	·08d.
3. Repairs and Maintenance	·25d.	·14d.	·07d.	·05d.
4. Depreciation at 5 per cent. minimum per annum ...	·17d.	·10d.	·06d.	·03d.
Total works cost ...	1·25d.	·85d.	·63d.	·51d.

enunciated will be apparent. The saving between a 60 per cent. load-factor and a 40 per cent. load-factor is nearly 20 per cent.; or in other

words, more than 20 per cent. more energy can be generated at the higher load-factor at the same cost. In many cases this will, of course, represent an increased revenue of many thousands of pounds per annum on the generating portion alone.

Disadvantages and Difficulties.

It is not my intention in this paper to critically examine many of the so-called disadvantages (as distinct from engineering and traffic difficulties) which have been urged as almost insurmountable obstacles to the carriage of goods on electric tramways. It is possible that they may be referred to in the discussion hereon, and I will then endeavour to reply to such points as may be raised. The most important drawback, however, has been stated to be the noise that would be created during the night by transporting heavy goods on rails through suburbs, thereby causing an almost intolerable nuisance to residents along the line of route. In my opinion this objection is very largely a matter of the imagination, to which undue importance has been attached. The lines of route which will be affected already form and are used as the highways for goods traffic during the night, and such highways which run out of, or through any town of importance, are paved with granite or grit setts. The disturbing and irritating noise thus caused by horse-drawn lorries is very considerable, and I think is far more accentuated than would be the case if all goods were conveyed on rails. Instead, therefore, of adding any additional disturbance in this respect, the conveyance on the tram rails would tend to mitigate an existing nuisance.

On the other hand there are undoubtedly many engineering and traffic difficulties to be surmounted. The principal of these may be stated to be as follows:—

1. The method of distributing goods to outlying districts, mills, warehouses, etc.
2. The difficulty of obtaining the sanction and approval of the local authority, property owners and frontagers to the laying of additional lines and sidings.
3. The arrangement of speed on both single and double lines of track, so as not to impede the ordinary passenger-car service.
4. The inauguration of the system.

With regard to the first of these problems, it will no doubt be profitable in many instances to lay down special lines and sidings, but in others some alternative method will have to be adopted. Even if the horse-drawn lurry cannot be dispensed with, the cost of transference in bulk from the electric truck to the lurry will be far less than unloading trucks in railway sidings. It will, of course, be necessary to provide depôts in each town for dealing with goods for isolated districts and local traffic. Such depôts would have to be provided with cranes, but there would be almost an entire absence of loose goods spreading about the floor area, which is so characteristic of railway goods sheds. Indeed, these depôts could be comparatively small, as the traffic would be

quick, exchanges rapidly effected, and the necessity for storage reduced to a minimum. Steam-propelled road lorries might replace horses in order to reach isolated places, but the use of such rolling stock would be entirely auxiliary, employed only for distribution in bulk. In cases where it is comparatively easy to obtain wayleaves for poles and line supports, such as in agricultural districts, it will be possible to form an efficient connection with collieries and mills by means of aerial rope-ways. These can now be made to take any curvature, and Mr. J. Walwyn White, of Widnes, who has made this subject a special study, states that the cost of a complete equipment, including power, may be taken at £1,000 per mile.

A very real and immediate difficulty is found in obtaining the sanction to lay additional lines and sidings. It affects both municipal and private enterprise alike, although, of course, the private enterprise is in much the worse position. Whether powers have been obtained under the Tramways Act or Light Railways Act, the whole course of the original procedure of applying for powers has to be repeated for every additional line required. It is true that the Board of Trade can exercise very limited powers in this respect, but after a concession has been obtained in the usual way, it should not be allowed to remain practically impossible to obtain such reasonable and beneficial extensions as special short lines to mills and sidings from the pre-determined track. Under the existing legislation, therefore, it is possible for a local authority or private individual to withhold in the most arbitrary manner the consent which is necessary to lay even a special siding into a works. This appears to me to be the most important condition to be remedied, and comprises the key to many of the other difficulties. I commend the earnest consideration of this matter to the Tramways and Light Railways Association, as a subject of real practical utility and urgency.

The arrangement of speed for goods traffic on both single and double lines of track, so as not to impede the progress of the passenger cars, is a matter of importance. Passengers cars have to be run at a high rate of speed, and it is obvious that in many cases it would be neither convenient nor economical to convey goods trucks at the same rate. It will, therefore, probably be found more convenient to convey very heavy goods principally during the night time, but for loads of not more than five tons per truck, no inconvenience to passenger traffic should occur. It must be remembered that passenger cars, although running at a high rate of speed, make frequent stops, and that in consequence the average rate will be not greater than that attained by a goods car. When, however, the traffic in goods becomes of considerable magnitude, it will pay to lay special sidings.

I have catalogued as one of the difficulties, the actual inauguration of the system, and it might well be considered a hopeless prospect if a complete solution of every detail were necessary before a commencement could be made. As a matter of fact, although I have dealt with many aspects, no such complete solution is required. Each case will present phases of purely local interest, and therefore in starting such a system I advise small beginnings. Many of the problems will thus solve themselves. We can start with fairly well standardised conditions

as regards track and overhead equipment. Interchange of traffic and through running in connection with contiguous undertakings will in nearly every case be a necessity, and the arrangements should follow the lead of the railway companies. Prior to any such necessity, however, it will probably be found advisable to make a commencement with local requirements. In many undertakings there exist large mills and factories providing cartage for hundreds of tons of goods weekly, and in some single instances as much as from 300 to 500 tons per week. Some of the collieries in the South Lancashire area have an output of from 500 tons to 1,000 tons per week for local use only, such as supplies to mills, gasworks, etc., and for which the usual cartage charge is 10d. per ton per mile. In such cases the railway is of no use whatever.

Conclusion.

In bringing this paper to a conclusion, I express the hope that the information which I have collected, and the discussion upon the points which I have raised, will be productive of some immediate experiments in connection with carriage of goods on tramways. I ask for the co-operation of the general manufacturing community, especially in an endeavour to obtain greater facilities from Parliament in extending existing systems for this purpose. A committee has recently been formed entitled the "Lancashire Transport of Merchandise Committee," having for its object the furtherance of a general scheme of goods conveyance on Electric Tramways in South Lancashire. The offices are in the Municipal Buildings, Liverpool, and among the members are the following gentlemen :—

Lancashire Transport of Merchandise Committee.

Sir John A. Willox	Liverpool.
Alderman Charles Petrie	Liverpool.
Alderman Frederick Smith	Liverpool.
Councillor Edward Lewis Lloyd	Liverpool.
Dr. Sephton, Manor House, Atherton	Atherton.
Mr. Borron, The Heights, Golborne, near Newton-le-Willows	Haydock.
Alderman T. E. Smith, Dun Withins, Heaton, Bolton	Bolton.
Alderman J. C. Gamble, Haresfinch, St. Helens	St. Helens.
Joseph Berry, Albion House, Swinton, Manchester	Swinton.
Thomas Dennett, Derby Street, Prescot	Prescot.
William Sharrock, Harvey House, Gathurst, near Wigan	Pemberton.
David Dove, Dove Leigh, Hall Lane, Hindley	Hindley.
Alderman T. R. Greenough, Beechwood, Leigh	Leigh.
T. H. Thomas, Mersey View House, Halebank, Widnes	Whiston.
Thomas Macleod Percy, Cinnamon House, Ince, near Wigan	Ince.
W. B. Richardson, Sunny Bank, Bolton Road, Farnworth, R.S.O.	Farnworth.
William Valiant, Gerard Street, Ashton-in-Makerfield.	

Alderman H. Chadwick, Crossbank House, Manchester Street, Oldham.
W. J. Tomlinson, 6, Church Street, Darwen.
H. E. Clare, Lancashire County Council, Preston.
Mr. A. S. Giles, Manager of Tramways, Blackburn.
A. E. Johnson, Bickershaw Hall, near Wigan ... ... Abram.
Geo. H. Cox
Charles Lancaster } Chamber of Commerce.
Colonel James Goffey
John Robinson, The Grange, Haydock, St. Helens ... Golborne.
Alderman J. W. Wareing, Bedford House, Widnes ... Widnes.

It will be apparent from this very representative committee, that the interest in the scheme does not centre in any one undertaking or portion; on the contrary, each undertaking has interest in common with the others, and the extension or development of the traffic on any portion must beneficially affect the remainder.

As a final word, I also take this opportunity of expressing the opinion that it would be to the advantage of the railway companies to co-operate with the tramway undertakings. Although at first sight the proposals described herein may appear entirely antagonistic to and competitive with the railways, yet in reality this scheme may be of great advantage to them. It will obviously affect the short-distance goods traffic on railways, but while taking away with one hand it may give twofold with the other. The tramlines would act as important feeders to the railways, bringing goods and produce to such centres and with such dispatch for conveyance for long distances. Something in this direction has already been accomplished on behalf of passenger traffic.

The South Lancashire Tramways Company have arranged with the Great Central Railway Company to book passengers and parcels through by their electric cars from Leigh to St. Helens, Wigan, Manchester, etc. The traffic will be conveyed by car to Lowton St. Mary's, thence by Great Central trains. Such co-operation between a tramway and a railway company is somewhat new in this country, but another example is that brought about by the recent arrangement between the London United Tramways and the Underground Electric Railways Company of London. In the latter case, however, to a large extent the capital of the tramway company is held by the railway company. In both cases the results to the public and the shareholders ought to be very satisfactory.

APPENDIX.

RHEINISCHE RAILWAY COMPANY, DÜSSELDORF.

GOODS TARIFF BY THE LIGHT RAILWAY.

Conditions for Forwarding.

The receiving and forwarding of small freights is subject to the following regulations, and to the fixed tariff as set forth herewith, and also to the conditions laid down by the State Railways. It is further subject to the regulations laid down in the "Traffic Orders for the German Railways," the "German Railways Goods Traffic, Part I.," the "Tariff Regulations and Classification of Goods," and the "extra tariffs," as far as they refer to small goods-carrying.

The following will not be forwarded :—

(*a*) Corpses and animals.
(*b*) Articles over 8 metres in length.
(*c*) Those articles enumerated in Part "B" of "Traffic Orders for the German Railways" (inflammable and explosive articles).
(*d*) Such objects which present more than ordinary difficulty in dealing with.

The times of the trains for each stopping-place are specially placarded up.

On Sundays and public holidays there will be no goods traffic. On such days milk only will be forwarded.

Days are considered in general as holidays where the local authorities allow the men working in public places the day off.

The drawing up of a freight bill can be made similar to the form used on the State Railways.

Principles upon which the Freight is Reckoned.

The freight is calculated in kgs. Goods under 20 kg. in weight count as 20 kg., and each fraction above 20 kg. shall count as 20 kg.

The freight will always be charged up to 5 pfg., and over this will be charged as 10 pfg.

There are two different freight tariffs, according to whether the goods come under the heading "small freight" or "market goods."

Under "market goods" are understood to be those which are produced from the cultivation of the land, and are being sent to the market. (All description of vegetables, fruit, potatoes, etc.)

The smallest charge for forwarding is 40 pfg.

Small freight will be forwarded in accordance with the tariff for same, the smallest charge being 30 pfg.

Light but very bulky goods will be charged 50 per cent. extra, and must consist only of those enumerated in the "German Railway Goods Tariff." The smallet weight will be reckoned to 30 kg.

Tariff for the Forwarding of Small Freight Goods.

Freight per 100 *kg.*

From and to	Krefeld. General small freight. m. pf.	Krefeld. Reduced-rate small freight. m. pf.	Fischeln. General small freight. m. pf.	Fischeln. Reduced-rate small freight. m. pf.	Osterath Hoterheide. General small freight. m. pf.	Osterath Hoterheide. Reduced-rate small freight. m. pf.	Forsthans Meer. General small freight. m. pf.	Forsthans Meer. Reduced-rate small freight. m. pf.	Büderich. General small freight. m. pf.	Büderich. Reduced-rate small freight. m. pf.	Oberkassel. General small freight. m. pf.	Oberkassel. Reduced-rate small freight. m. pf.	Düsseldorf. General small freight. m. pf.	Düsseldorf. Reduced-rate small freight. m. pf.
Düsseldorf ...	— 44	— 36	— 40	— 33	— 33	— 28	— 27	— 24	— 24	— 21	— 18	— 16	—	—
Oberkassel ...	— 39	— 32	— 34	— 29	— 28	— 24	— 21	— 18	— 19	— 17	—	—	— 18	— 16
Büderich ...	— 32	— 27	— 28	— 24	— 21	— 18	— 16	— 14	—	—	— 19	— 17	— 24	— 21
Forsthans Meer	— 29	— 25	— 25	— 22	— 19	— 17	—	—	— 16	— 14	— 21	— 18	— 27	— 24
Hoterheide ...	— 23	— 21	— 19	— 17	—	—	— 19	— 17	— 21	— 18	— 28	— 24	— 33	— 28
Fischeln ...	— 17	— 15	—	—	— 19	— 17	— 25	— 22	— 28	— 24	— 34	— 29	— 40	— 33
Krefeld ...	—	—	— 17	— 15	— 23	— 21	— 29	— 25	— 32	— 27	— 39	— 32	— 44	— 36

The following articles will come under a reduced rate :—

(1) Wood, and wooden articles of all sorts.
(2) Metals, and metal wares.
(3) Iron, steel, iron and steel wares.
(4) Scrap metal.

When larger weights are to be forwarded, the following reductions are allowed :—

On weights from	3,001–3,500 kg.	a reduction of	10%	of the freight.
Do.	3,501–4,000 kg.	do.	15%	
Do.	4,001–4,500 kg.	do.	25%	
Do.	4,501–5,000 kg.	do.	40%	

EXCEPTIONAL TARIFF.

Comes into force for those goods which arrive at Düsseldorf by water, and are immediately delivered on to the Light Railway—also *vice versâ.*

Freight per 100 *kg.*

From	KREFELD.	FISCHELN.	OSTERATH.	HANS MEER.	BÜDERICH.	OBERKASSEL.
	20·1 km.	17·3 km.	13·3 km.	9·3 km.	7·3 km.	3·3 km.
Düsseldorf	26	24	20	16	14	11

TARIFF FOR FORWARDING OF MARKET GOODS.

Per 100 *kg. Weight.*

From and To.	HEERDT LORICK.	BÜDERICH.	FORSTHANS MEER.	OBERATH BOVERT.	OSTERATH HOTERHEIDE.	FISCHELN.	KREFELD.
	pf.	pf.	pf.	pf.	pf.	pf.	pf.
Düsseldorf	30	35	40	45	50	60	70
Krefeld ...	—	30	45	40	35	20	—

Basis of Calculation of the Freight.

	Per Kilometre and 100 kg.
From Lorick to Düsseldorf	5·5 pf.
„ Büderich	5·0 „
„ Forsthans, Bovert, Hoterheide...	4·0 „
„ Fischeln and Krefeld	3·5 „
„ Büderich and Forsthans Meer to Krefeld ...	4·5 „
„ Bovert, Hoterheide, and Fischeln, to Krefeld	5·5 „

LIGHT RAILWAY, FORSTHANS MEER—UERDINGEN.

I. Direct Traffic. Tariff for Freight Goods.

Freight per 100 *kg. Lowest Possible Charge,* 30 *pf.*

From and To	To and From							
	Strümp.		Latum-lank		Stratum.		Uerdingen.	
	General.	Reduced rate.	General.	Reduced rate.	General.	Reduced rate.	General.	Reduced rate.
	m. pf.	m. pf.	m. pf.	m. pf.	m. pf.	m. pf.	m. pf.	m. pf.
Düsseldorf ...	— 32	— 27	— 36	— 31	— 41	— 35	— 47	— 39
Oberkassel ...	— 27	— 22	— 31	— 26	— 36	— 30	— 42	— 34
Büderich	— 21	— 17	— 25	— 23	— 30	— 25	— 36	— 29
Hans Meer ...	— 17	— 15	— 21	— 19	— 26	— 23	— 32	— 27
Osterath	— 24	— 20	— 28	— 24	— 33	— 28	— 39	— 32
Fischeln	— 30	— 25	— 34	— 29	— 39	— 33	— 45	— 37
Krefeld	— 34	— 28	— 38	— 32	— 43	— 36	— 49	— 40

II. Local Traffic.

Freight per 100 *kg. Smallest Charge for Forwarding,* 30 *pf.*

Strümp	— —	— —	— 17	— 15	— 22	— 19	— 27	— 23
Latum-lank ...	— 17	— 15	— —	— —	— 18	— 16	— 22	— 20
Stratum	— 22	— 19	— 18	— 16	— —	— —	— 18	— 16
Uerdingen ...	— 27	— 23	— 22	— 20	— 18	— 16	— —	— —

MARKET GOODS.

Freight per 100 kg. Smallest Charge for Forwarding, 40 pf.

	From and To			
To and From	STRÜMP.	LATUM-LANK.	STRATUM.	UERDINGEN.
	m. pf.	m. pf.	m. pf.	m. pf.
Düsseldorf	— 40	— 45	— 50	— 60
Krefeld ...	— 45	— 50	— 60	— —

RHEINISCHE RAILWAY COMPANY,
LIGHT RAILWAY—DÜSSELDORF-KREFELD. *Form I.*

CONDITIONS TO BE OBSERVED FOR THE REGULAR FORWARDING OF MILK.

1. *Arrangement of Requirements.*

Arrangements for the regular forwarding of milk from one station to another, together with the returning of empty milk-cans by special trains, can be made monthly, as long as the delivery takes place daily and the amount of milk carried during the course of the month comes to at least 500 litres, or the freight for this quantity be paid for. This does not hold good for those who begin forwarding after the month has once started. The forwarding arrangements can commence or finish on any day.

2. *Senders' Notification.*

Persons desirous of making arrangements for forwarding must, after first becoming acquainted with the regulations, hand in particulars of the nearest stopping-place, at least three days before they wish the forwarding to take place. There is no charge made for this.

3. *Security, Fines, Payments.*

The consignor must deposit a sum equal to one and a half times the monthly freight account as a security for payment of freight. Interest on this amount will not be allowed by the management, but this sum will be returned at the end of the month after the first account has been paid. Should the freight reach or overstep the amount provided for by the security (in the course of a month), then the consignor must pay the corresponding amount upon being called upon to do so by the station official, otherwise further deliveries will not be executed.

4. *Descriptions and Markings of the Vessels.*

Vessels to be used for forwarding milk must be portable, and possess a tight cover, so that the milk cannot flow out even if the cans fall over.

The capacity of a vessel shall not exceed 40 litres, and must be plainly written upon it, together with the weight of the vessel. An official calibration or testing of capacity must not be necessary on the part of the railway company.

Each vessel which is intended for milk transport must have a massive brass label, engraved distinctly (that it may be easily read by artificial illumination), giving the name of the consignee and the receiving station, as well as the name of the consignor and sending station. The labels are to be removed by the consignor if at any time they should become illegible. If milk should be transported in small containing vessels (for instance, glass bottles) and placed in boxes or cases, each case must be filled up and must not weigh more than 40 kg. They must be strongly constructed, and have on each side secure handles for lifting. On the cover of each case must be distinctly written, on one side the greatest weight of box filled up completely, on the other the weight of same with empty bottles. Before entering into the contract the box or cases must be sent to the station (stopping-place) in order to prove that the weights as given are correct; further, each case must be labelled with the consignee's name and station, as well as the consignor's name and station.

Vessels or cases of milk which do not correspond to the foregoing regulations will not be accepted.

In order to easily recognise the home station for the empty milk-cans it would be advantageous for each stopping-place to have a special colour, the colour to be painted on the covers of the cans.

Milk senders are therefore requested in their own interests to arrange this, so that each stopping-place may be thus recognised, and there will be little chance of cans going astray.

5. *Delivery Note.*

The consignor has to deliver up daily at the time that he delivers the milk to the sending-off station a written statement (milk delivery note) in duplicate, in which is stated—

1. How many vessels he is sending.
2. How many litres of milk the vessels contain.
3. What is the weight of the cans.

The milk delivery note must be procured by the consignor himself, or may be purchased at the stopping station. Bills of freight are unnecessary, as the milk delivery note takes its place.

6. *Incorrect Particulars of Weight.*

Should the quantity of milk be more than is stated on the milk delivery note, the consignor will be fined, besides the amount short, four times the total amount of the freight sent by that train.

7.

The loading and unloading of the milk vessels at the stopping-places is done by the sender and receiver respectively, under the supervision of the light railway official.

8. *Delivery to more than one Consignee.*

One consignor may deliver milk vessels to a number of consignees. In this case, the consignor must make arrangements with a representative at the receiving station so that he receives the whole consignment. Otherwise he must send on as many notes as there are consignees.

9. *Time of Delivery and Collection.*

Carts for the collection of full cans must not arrive at the stopping-places earlier than a quarter of an hour before the train arrives by which he is sending his consignment.

Empty cans likewise may not be brought to the stopping-place earlier than a quarter of an hour before the train is due in by which he intends returning the cans.

The return of the empty vessels takes place without any accompanying papers, solely by the marking on the cans.

10. *Calculation of Freight.*

For this calculation there is necessary—

(*a*) The weight of the forwarded milk, including weight of cans.

(*b*) Half the weight of the returned cans.

Every consignment will be entered up daily, particulars as to quantity and weight being taken from the milk delivery note. All accounts for milk delivery will be made up to the last day of the month, the freight being reckoned for the total quantity delivered, which must come to at least 500 kg. By regulating the weight of milk, one litre is assumed to be equal to one kg. weight. Further fractions of 10 kg. are reckoned as 10 kg. Accounts are made up to 10 pfg. amounts less than 5 pfg. counting as nothing, and amounts exceeding 5 pfg. as 10 pfg.

11.

Accounts are received by the consignors on the first day of every month. Payments must be made within three days at the latest. Should the consignor be behind in his payment, then no further milk will be accepted for forwarding.

THE COMMITTEE.

Düsseldorf. *The Rheinische Railway Company.*

I agree to the foregoing regulations, and enclose herewith copy of my requirements. day of , 190 .

....

DISCUSSION.

Mr. H. A. EARLE (*Chairman*), in opening the discussion, said that the difficulties in the distribution of the goods had not been fully stated by the author, although, no doubt, Mr. Gibbings knew of their importance. If the method of "house-to-house" delivery were attempted the rate of transit would be very slow, and passenger traffic would be Mr. Earle.

Mr. Earle. seriously impeded. A possible solution might be found in the establishment of large distribution centres. An important feature of any scheme should be co-operation with the great railway companies in the carriage of through traffic over great distances. The table referring to the Trade of Liverpool needed the qualification that the railway companies and other carriers did not necessarily handle the goods immediately, for a very great quantity found its way into warehouses, and remained there for varying lengths of time. He asked for information concerning the costs of transport, particularly the economies that were to be expected upon deliveries within distances say of thirty miles; also what were the inducements held out to investors in such undertakings. Another point was the maximum load to be anticipated per car. On railways three tons appeared to be a maximum, and yet the author stated in his 11th condition that the maximum should not be less than nine tons. How did he propose to raise the maximum to this figure?

Mr. Hill. Mr. G. HILL said that the results anticipated would be deferred for many years, owing to the delay arising out of the jealousies of the several local authorities, whose powers of obstruction under existing circumstances were incalculable.

Mr. Sheffield. Mr. T. W. SHEFFIELD, after referring to the question of vibration, alluded to the success attending the Detroit system, in large measure due to the absence of restrictive bye-laws and other regulations so generally imposed upon all such undertakings in this country. The maximum load proposed by his brother's firm—Messrs. Sheffield and Twinberrow—for tram vehicles was 15 tons.

Mr. Day. Mr. DAY asked if Mr. Gibbings had any scheme to adjust the terms for the interchange of through traffic between districts thinly populated and densely populated centres. This was a matter now under consideration, and affected the question of development very acutely. He should be glad of any assistance in its settlement.

Mr. Lindley. Mr. LINDLEY referred to the debate on the economies attending the use of large wagons, and considered that the decision of the L. & N. W. R. directors was scarcely fair. If the difficulties of collection and distribution were so great, and the resulting average weight so small, it seemed to point to the necessity for the assistance of auxiliary companies in the work of collection and distribution. Examples of such assistance could be found in the work done by such firms as Messrs. Sutton, Messrs. Pickford & Co., etc.

Mr. Twinberrow. Mr. TWINBERROW remarked that engineers are generally compelled by surrounding circumstances to adopt a solution of their difficulties which they know is not technically the best. In this country the "vested interests" that have to be respected, and the inordinate powers of obstruction that individuals possess were the cause of much bad engineering. He then discussed the present methods of handling coal, and concluded that the existing methods would disappear.

Mr. Wells. Mr. G. J. WELLS thought that much might be learnt from a consideration of the existing mismanagement of the great railway companies, and insisted upon the importance of dealing systematically with the arrangements necessary to cultivate traffic. After giving an example

of how a growing trade was killed by the simple expedient of altering the running of two trains so that a previous connection between a rural district and London ceased, he suggested that traffic managers should have as assistants men who knew the wants of traders and so could prepare the way for the development of new business, instead of so operating that any such growth was impossible. He thought that the circumstance of finding the S. E. R. being quoted as an example of rapid handling of goods was worthy of more than passing note. If he had not actually seen the method in use, he should certainly have queried the author's veracity on that point. The next speaker asked for information concerning the relative costs of carriage by motor-wagons, horse-drawn lurries and tram-vehicles.

Mr. F. SELLS asked if Mr. Gibbings had any information to give concerning the probable increase in maintenance charges. The carrying of goods can only pay if carried out on a large scale. It is then inevitable that traffic should proceed constantly—passenger by day, and goods by night—and he would therefore like to know how and when the necessary repairs to both the permanent way and the overhead equipment would be carried out. Mr. Sells.

Mr. A. H. GIBBINGS stated, in reply, that it would not be possible to arrange for a house-to-house delivery in connection with heavy goods traffic as suggested by the Chairman, nor would the necessity arise. He pointed out in his paper that depôts would have to be established in the various districts, but that in those cases where it was possible to run special sidings into mills, warehouses, etc., much economy in time and labour would be effected. The Chairman was wrong in assuming that three tons per truck was the maximum carried on railways, that figure being the average weight per truck. The difficulty which Mr. G. Hill experienced should be met by some further special legislation in order to prevent local authorities from exercising an absolute veto. Mr. Gibbings.

Mr. Gibbings mentioned several cases of tram-lines where the gauge was less than the standard and which were being operated electrically. On the subject of terms of agreement between the various authorities, the only suggestion he had to offer was to follow the example of the railway companies which appeared to satisfy the several authorities concerned. He next defended the methods suggested in his paper for handling goods in bulk, as being the most economical way. Mr. Sell's query he would answer in the future when the necessary data had accumulated. He felt that the several other difficulties that speakers had suggested would be capable of solution as they arose. If everything had to be solved before an undertaking was initiated, he ventured to think that the rate of progress would be even less than it was.

BIRMINGHAM LOCAL SECTION.

NOTES ON MOTOR-STARTING SWITCHES.

By A. H. Bate, Associate Member.

(*Paper read at Meeting of Section, April 29th, 1903.*)

Introduction.

In view of the growing importance of electric motive power, it is surprising that the accessories of the electric motor have so seldom been brought forward for discussion before the engineering societies. Whatever may be the reason, it certainly is not because such apparatus has reached a state of perfection; indeed, the wide divergence of designs would suggest that the subject is still in the quasi-experimental stage. The motor itself has become a fairly constant quantity, and a dozen machines by as many makers will show more points of similarity than of contrast.

The motor starter is at best a necessary evil. It is distinctly a drawback to have to spend one-tenth or more of the price of the motor for an apparatus to start it, and this may increase to a quarter or even to as much as half the cost if we wish to use the starting resistances for obtaining a variable speed. There is a very natural tendency to sacrifice good workmanship to cheapness in a part of the plant that is only in use for half a minute three or four times a day, and this no doubt accounts for the fact that cheaper work, both in the resistances and in the switch itself, is used for motor starters and controllers than would be accepted for any other purposes. On the Continent and in America more attention has been paid to this subject than has been the case in this country. Most of the improvements that have been made from time to time have come to us from abroad, but unfortunately these ideas have been embodied in switches of such a flimsy description that every one must have felt the incongruity of using them in conjunction with the solidly built motors that we make in this country. Until recently few English manufacturers have laid down standard lines of starters. For the most part they have been content to manufacture one by one and in small quantities as ordered, and under these circumstances have naturally fallen behind their foreign competitors, who have specialised in this class of work and have manufactured in quantities. Motor starters have to meet so many varied conditions that it is not easy in any case to combine all the requirements in a few patterns, and in this country the difficulty has been accentuated by the rules of the insurance offices and the very stringent and sometimes impossible regulations made by the engineers of the public supply companies. For instance, it is stipulated in some towns that the current shall not exceed five amperes on the first contact, with five-ampere steps up to full current. In other

places ten amperes are allowed, and in others fifteen amperes. In addition to this, some engineers require the switchwork to be protected by an iron case, others require a double-pole switch to be interlocked with the starting lever, or perhaps a slow motion has to be provided to prevent the current from being turned on too rapidly. All these conditions are unnecessary for the proper working of the motor, and it is not surprising that manufacturers have waited for things to settle down a little before committing themselves, since any design of switch that embodied all the requirements of all the public authorities would be too complicated to work and much too expensive to sell.

Next to the commutator of the motor, the starting switch is generally the part of the plant that gives most trouble, and this is due more often to the lack of a clear understanding between the maker and the installer as to what are the actual conditions of use than to any inherent defects in the design or construction. For example, one finds starters with resistances wound on asbestos tubes exposed to the weather; resistances embedded in sand or cement with switchwork of the lightest description used where starting and stopping is of frequent occurrence; or, to take an example of over-precaution, a switch with a costly slow-starting mechanism completely protected by a cast-iron case and installed in a dynamo-room. In no part of their specifications are some of our consulting engineers so indefinite as in the clause relating to the starters. After a detailed specification for the motor itself, one comes to a brief phrase about a suitable starter, without any indication of the conditions that settle which of the many available types will best meet the case. The object of this paper is to compare a few of the many forms of starting rheostats that are being made, and to outline the principles involved, in the hope of raising a discussion on the subject that may help to guide us in a choice of the best apparatus for use in the various conditions that have to be met.

Rating of Resistances.

There are three types of resistance in use, and for convenience we may name them:—(1) The *radiation* type, in which the resistance spirals are exposed to the air and the heat is dissipated by radiation and convection; (2) the *absorption* type, in which the wires are embedded in sand or cement and the heat is quickly absorbed by the sand and conducted away slowly; and (3) liquid resistances, in which the heat is absorbed by the electrolyte itself. In considering resistances in relation to heating, we may compare the conditions to those of a hoist motor. There is heavy duty for a short time, followed by a longer or shorter period for cooling down again. The German Institution of Electrical Engineers has recently framed a set of rules for the rating of motors which, I believe, is being pretty generally adopted on the Continent. They divide motors into three classes, according to the nature of the load for which they are intended. Thus, motors for *intermittent* work must give the full marked horse-power for one hour; and those for *continuous* use, for ten hours without overheating. There is a third class of rating provided, intermediate

between these two, for what is called *short time* use, in which the motor may be run at full load for two or three hours, or more, as the case may be, followed by a period of rest. In each case the class of rating and the time at full load must be marked on the output plate. The advantage of such a definite system of rating and labelling motors will be obvious to every one, and particularly to those who have to meet the customer who thinks he is being defrauded because a seven-horse-power motor for driving his shafting costs more than a ten horse-power motor for the crane. The question of the rating of motors does not come within the scope of this paper, but the matter has been mentioned because a similar classification may with advantage be applied to motor starters. Thus we get :—

Class 1. *Occasional use*, where a sufficient interval is allowed between the times of use to permit the resistances to cool down to air temperature. This represents the majority of cases, and in the writer's opinion the resistance should be able to carry the full-load current safely for at least half a minute, and carry an overload of 20 per cent. of current—that is, 50 per cent. of watts—for, say, ten seconds.

Class 2. *Frequent use*, where the interval is not sufficient to allow of complete cooling, or where the time taken in attaining full speed is unusually prolonged for any reason. The time for which the resistances would carry full-load current without overheating would be stated on the name-plate.

Class 3. *Continuous use* would include speed regulators.

WIRE RESISTANCES.

For the first class of work—that is, for occasional use—the absorption type of resistance is not only the cheapest but also the best. It has the disadvantage of being, perhaps, more difficult to repair than some other forms, and this is especially the case when cement is used to cover the wires instead of sand, but this slight drawback is more than compensated by the security that is gained by the cast-iron case protecting the wires from mechanical injury and from damp. Unfortunately this type of resistance is viewed with a certain amount of suspicion by many engineers. The resistances being out of sight, the work is sometimes very slipshod. For instance, iron nails fitted in holes in the slate base are used to support the wire spirals, and though they may be sufficient for the purpose, it is not a method of construction that is calculated to inspire confidence among men accustomed to engineering work. When properly rated, the absorption type will stand overloads for a short time just as well as the radiation type of resistance. When the wires burn out it is generally because they have been cut too fine for the work, or because they are being used for a class of duty to which they are not suited. When the operation of starting is repeated at short intervals the sand or cement does not have an opportunity to dissipate the heat, and sooner or later the wires get burnt. When the wires are exposed to the air it is possible to tell by inspection whether they are being overheated, but with absorption resistances one has to trust blindly in the maker's statement. In order

to inspire confidence and to insure against overrating a recognised method of testing such apparatus is very desirable. The writer would be satisfied with a starter that would pass the following test :—

A current 20 per cent. in excess of full-load current to be passed for a time depending on the size of the motor, the operation to be repeated at intervals of twenty minutes with full-load current without burning the surface of the wires, the time of passing the current being fifteen seconds for motors up to one horse-power, thirty seconds for motors up to two horse-power, and one minute for larger powers.

Liquid Resistances.

For use in exposed situations and for large powers a starter with a liquid resistance has many advantages, and if proper care is given to the design it will give less trouble on the whole than a wire-wound resistance. It is true that in the types with liquid held in an open box it evaporates and needs replenishing from time to time, but this small amount of attention is more than balanced by having a resistance that will not burn out however heavily it is overloaded. The objections that are urged against it are: *First*, bad insulation caused by the liquid creeping and spraying on to the porcelain insulators. This need not happen if the box is covered and the insulators are placed where they can be easily got at for cleaning. *Secondly*, too heavy a current at the moment of starting. This refers to motors working on some of the town lighting mains, or to small high-voltage motors for which the liquid resistance is certainly not suited. For powers of five horse and over at 230 volts, or for ten horse-power at 500 volts, the resistance can very easily be regulated to give no more than full-load current for the start, and this, if it does not satisfy the station engineer, is quite good enough for any properly constructed motor. *Thirdly*, the generation of explosive gases has alarmed some of our fire insurance experts; but when one remembers the very small volume of gas that is generated at each operation, it is difficult to believe that an explosion has ever been caused by this means, unless the resistance was not provided with a short-circuiting switch contact for the full-on position.

In order to give satisfaction to the general user, the liquid starter must be provided with an overload and a "no-volt" automatic release, just as has been done with the wire-wound switches. If a "no-volt" release cannot be used conveniently, the main double-pole switch must be interlocked with the resistance, so that the current cannot be switched on while the resistance is cut out.

The Sandycroft Foundry Company, Limited, have introduced a liquid resistance starter that has some novel features, and is undoubtedly a great advance on the old-fashioned makeshifts that we have been used to see. The liquid, which consists of common soda and water, is contained in a tightly closed cast-iron case, and instead of moving the plates in the usual way, the whole cylindrical case is rotated on an insulating bearing. A no-volt and also an overload automatic release is provided, and as the overload release acts not only in the full-on position, but also during the operation of starting, the

current cannot be turned on too suddenly. The makers state that at the moment when the plates enter the liquid the current is only from five to ten amperes in the case of a 10 H.P. starter, and that sufficient plate area is provided to pass the full-load current before the liquid is short-circuited. By completely enclosing the liquid, the evaporation is so much reduced that it need only be renewed at very long intervals.

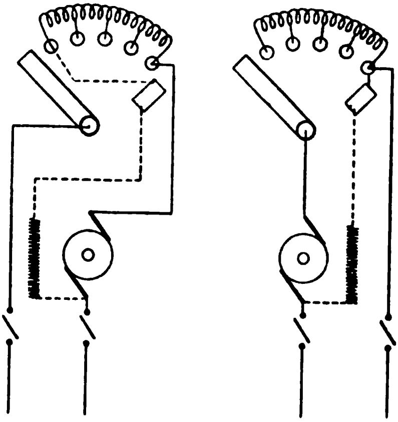


FIG. 1.

CONNECTIONS.

There seems to be a difference of opinion as to the best way of connecting the resistances and the motor. The majority of makers arrange their switches for the armature to be connected to the last contact of the resistance. The main is then joined to the starting lever, and the shunt magnet is connected through the "no-volt" coil to the first contact of the resistance. The current is applied simultaneously to the magnets and armature, so that as the field builds the torque is applied gradually. Moving the switch lever over cuts the resistance out of the armature circuit and puts it into the field circuit. The shunt windings are permanently connected through the no-volt coil and resistances across the brushes, so that the self-induction kick spends itself gradually as the motor slows down. An alternative method is to connect the armature to the starting lever and to join both the main and the shunt magnet wires to the last or "full-on" contact of the resistance. The field is then excited when the main switch is closed, and the motor is started and stopped without demagnetising the magnets. When the lever touches the first contact the full torque is applied instantly to the armature, and this causes undue strains on the moving parts. A more serious weakness of this method of connection is that when the motor is at rest with the starting switch in the "off" position, the magnet windings are not connected across the brushes, and if the main switch is opened the kick of the magnets will be very likely to rupture the insulation of the field spools.

Switch Work.

In discussing the type of resistance that is best suited for a particular purpose, we found it convenient to distinguish between frequent and occasional use, and a moment's consideration will show that the same classification can be applied with advantage to the switch work. Where the switch is used often, as, for instance, with a printing press or with a machine tool, too much stress cannot be laid on the importance of strong construction with the contacts and all wearing parts renewable from the front; but for what we have called occasional use—the driving of a line of shafting, for instance, or a butcher's sausage machine—the use of a heavy switch construction is not necessary. The business of the engineer is to provide the best all-round economy, and it is possible to waste money by using plant that is more substantial than is necessary, just as certainly as it is a temptation to use stuff that is too light. The danger is that, if we admit a light switch construction in certain cases, some matters of vital importance may be neglected in a struggle for cheapness. For instance, there are switches on the market which no one would consider too substantial in their construction, whatever else might be said of them, in which the main current passes through the iron arm of the switch lever. There would be no objection to this if the contacts to iron were short-circuited in the "full-on" position instead of being, as they are, left always in circuit. Large numbers of these switches have found their way into this country, where they may be seen installed with a double-pole switch having drawn copper parts which are probably not allowed to carry more than eight hundred amperes per square inch, according to specification.

Switches that are to be exposed to the weather must have a watertight case not only for the resistances, but also for the switch work. The ordinary patterns of ironclad starters are admirably fitted to keep the damp away from the resistance wires, but they are seldom designed so as to admit of the addition of a cast-iron cover over the switch front, although this could easily be arranged for as an addition to standard patterns and at a very small extra cost.

Where covers are used the switch lever is sometimes brought out through a slot in the top of the case. It may cost a few shillings more to provide a separate handle bushed through the cover and engaging by a pin with the switch lever inside, but it is the only way to make a watertight job.

Examples of Starters.

Messrs. Cowans, Limited, of Manchester, are making a watertight switch on very novel and interesting lines. The resistances are made of strip coiled in a cast-iron box, each box containing one unit of resistance. These boxes are built in two tiers, and a screw with a quick pitch moves a connecting piece over the contact blocks that are attached to the resistance boxes. If a resistance burns out, a new one can be inserted with a minimum of trouble. The screw gives a slow motion to the starter, and this, combined with the waterproof and

generally substantial construction, makes it particularly fitted for places where it is exposed to careless handling.

Another example of a switch in which the resistance is divided into easily renewable units is the crane controller made by the Electric Controller Supply Company, of Cleveland, U.S.A. Each resistance is complete in itself, and is attached to the slate base by a hexagon copper nut which serves as a contact stud. The resistance wires are wound on asbestos tubes, and the apparatus is therefore only suited for dry positions, since asbestos absorbs water readily from the atmosphere, and loses its insulating properties if used in exposed places. The current passes through an iron rod that supports the asbestos tube, and the makers claim that iron is better than brass for this purpose, because it is magnetised by the current through the resistance spiral, and so provides a magnetic blow-out for the arc.

A departure is made from the usual electro-magnet for retaining the switch-arm in the full-on position in a starter supplied by the International Electrical Engineering Company. Instead of placing it at the free end of the switch lever, the "no-volt" coil is wound on an iron bobbin that forms the bearing of the switch spindle. When the starting resistances are also used to control the speed, this arrangement provides a no-volt release action that will hold the lever against the pull of the spring, not only on the last contact, but also on any intermediate position. Messrs. Ellison, of Paris, also make a combined starting and speed-regulating switch, in which the ordinary pattern of no-volt magnet is used in conjunction with two levers, one of which controls the current, and the other is held by the no-volt magnet against the action of the spring. When the current is switched off, this lever flies back and carries the other lever with it.

Messrs. Veritys, Limited, have made two standard lines of starters, one with the resistance spirals embedded in sand for starting on light load, or for what we have called occasional use on full load; and another construction for frequent use and for exceptionally severe conditions, in which the radiation type of resistance is used, the wire spirals being coiled round porcelain insulators and exposed to the air.

When an overload release magnet is not provided, the switch is made on the usual lines, but the shunt field connection is joined, not only to the first contact of the resistance switch, but also to the frame of the no-volt magnet coil, so that when the switch is in full-on position the starting resistances are not left in the field circuit, but are short-circuited. In the larger sizes, when the shunt current is too great to be safely passed through the iron magnet frame, a separate contact stud is provided for this purpose. The starters that are provided with an overload action have a single-pole switch in the armature circuit that is closed by moving the starting lever to the position in which the resistance is all in circuit, and is then held closed against the action of a spring by the no-volt magnet. The overload magnet acts in the well-known way by short-circuiting the windings of the no-volt magnet. If the starting lever is moved over too rapidly, the overload operates and releases the main switch, which then breaks the circuit, the arc being taken by carbon blocks. A unique feature of this starter is that the

spring pulls the switch lever to the "full-on" position, instead of to the off position as usual. In the larger sizes the contact plates are renewable from the front of the slate, and a carbon brush is used on the contact lever to protect the laminated copper brush and the part of the contact plates on which it moves from being roughened by the sparks.

Automatic Starters.

Motors driving pumps for charging hydraulic accumulators or for filling tanks require a special form of switch that will start and stop the motor automatically as the level varies. A common arrangement is to make the motion of the float throw over a switch in circuit with a solenoid. The starting lever is then moved over the contacts by the motion of the core as it is sucked into the solenoid. In order to give the necessary slow motion to the switch lever, dash pots have to be resorted to, and every one knows the troubles they introduce, either by wearing loose and working too fast, or sticking with a little bit of grit. The weakness of the solenoid and dash-pot arrangement is that if the dash pot does stick, or if the contacts of the switch become roughened with the arc, there is no reserve power in the solenoid to overcome the extra friction. Messrs. George Ellison have introduced a starting switch for this class of work in which the motive power for moving the switch is provided by a small cylinder and piston connected to the water mains. When the motor is required to start, the movement of the float turns on a small two-way cock which admits water into the cylinder. As the piston slowly rises it first closes a double-pole main switch, and then proceeds to cut out the resistance step by step. When the tank is full the float again throws over the two-way cock—connecting the cylinder to the drain pipe. The piston then falls rapidly under the action of a weight, first inserting the resistance and then opening the double-pole main switch. To prevent the contacts from being roughened by the arc, a magnetic blow-out is provided.

In conclusion, let me say that in these brief notes no attempt has been made to treat the subject systematically or as a whole, but rather to mention a few of the points of interest that have cropped up from time to time in selecting starters for different purposes; leaving a more adequate treatment to those who are directly concerned in the manufacture of this class of switch—to whom by right it belongs.

Mr. J. C. Vaudrey said that a very great deal of ingenuity had been displayed in the manufacture of starting-switches. Speaking as with a central-station engineer's experience, he might say that in Birmingham they had 400 or more motors on the town circuits, and the bulk of them were controlled by starting-switches. Many of these had been in existence three or four years and, in his experience, had given comparatively little trouble. The object of the starting-switch was to protect the consumer from spoiling his motor, but it was also absolutely essential to prevent undue draughts of currents for the moment on the supply system. The minimum and maximum was purely a question Mr. Vaudrey.

Mr. Vaudrey. for the consumer. The maximum cut-out protected the consumer from an accident to his motor through overwork, the minimum cut-out protected the consumer should the supply system for any short period cease.

He thought that with very large and heavy machinery, which sooner or later would be put upon the supply system, the starting-switches such as shown by Mr. Bate would not be sufficient. In Birmingham they were now dealing with two or three large printing presses, and in addition to the starting-switch a system was applied which gradually increased the current, so that there was not a sudden draught on the supply system. This was not only a supplement to the starting-switch, but in reality became an essential part of such machinery, and probably for motors of 40 H.P. or 50 H.P., where any sort of regulation was required, it would be used. With the cheapening of the supply and the advent of large motors of 40 H.P. or 50 H.P., it was quite clear that something beyond a mere starting resistance became necessary, and there were two methods in vogue. One was to start through a motor-transformer termed a "teaser," which reduced the current to a low voltage with a corresponding increase of amperes; the current was switched on, in the first instance, to this "teaser," which was afterwards cut out when the necessary start had been made. The second method of driving was, he thought, one more likely to come into use. This was a parallel-series system, the motor being fitted with two armatures on one spindle for working in series or parallel; these were joined in series for making the start, and afterwards changed over in parallel when a higher speed was desired, or when the machine became fully loaded. By those means 50-H.P. or 60-H.P. motors were readily put on the mains without trouble. After emphasizing the importance of the exposed parts of starting-switches being covered up, and predicting that for large powers nothing else than the covering to be seen on a tramway controller would sooner or later be allowed in factories, Mr. Vaudrey said that such apparatus could not be too well protected, because in town systems all motors of 5 H.P. and above would have to be supplied at 440 volts or higher pressure. The tramway starting-switch was a type which might very readily be copied. They were handy and of a form that workmen could understand, and they were very substantial. He had frequently noticed that the gear and the handles of ordinary starting-switches were anything but strong, and not what the ordinary mechanic was accustomed to deal with. He did not know what the condition of the Woolliscroft water starter shown would be if the water boiled up unless there was a safety-valve.

Mr. Cowan. Mr. E. W. Cowan said that he quite agreed with Mr. Bates in his commendation of the absorption type of resistance as being the best. Properly made, it was by far the most mechanical form of resistance. The open spirals were necessarily weak, and the methods of supporting them difficult, and the economy in first cost was very considerable.

In connection with the starters made by his own firm, a test was recently made of the relative capacity of an open spiral resistance and a resistance of exactly the same length and size in every respect made in the form of their thermal capacity resistance. The result was that

Mr. Cowan.

while the spiral with 1 H.P. on it became red-hot in a quarter of a minute, the thermal capacity unit in two minutes showed no sign of any high temperature sufficient to cause it to radiate any light. That the absorption type of resistance had a very bad name with some of the consulting engineers in this country was due to the fact that a breakdown was such a serious thing, involving great loss when a motor was driving a large number of machines. The starting-switch made by his firm, which was shown by Mr. Bate, was one of nearly a hundred made for the railway shops at Pretoria. He was very much interested in the liquid resistance, and hoped to know more about it before he left the meeting. He should be surprised if the manufacturer had succeeded in getting no jump between the equivalent of the last stop of the resistance and all resistance out. It was very difficult to get it in liquid starters, and also, at the same time, to get sufficiently small current to start with. He thought liquid starters were better suited than any other form for hoist and crane work. There was of course the difficulty of corrosion, but in cases where the starters were in the hands of people who knew nothing at all about electricity, they should be as durable as they could possibly be made. Mr. Cowan pointed out that in his firm's starter the full field was on at the commencement. He thought the full field should come on at first so that the starting current was as small as possible. He would conclude with a list of points that he thought every motor starter of any size should conform with. He agreed that excessive finish was out of place; what was wanted was substantial construction. He thought the starter should be made on the same lines as the motor, with the same regard to durability, and that that would be cheapest in the long run. All the working parts should be enclosed, not only in the interests of safety, but because in workshops switches with parts exposed got broken. The other points were as follows :—

(1) Designed as a machine, and not as an instrument, and equally capable of standing the same treatment as the motor it is to control. (2) Resistance units of uniform shape and dimensions, and interchangeable, connected directly to the contact studs by lugs on the units. (3) Resistance units either of the ventilated type for controlling purposes, or of the capacity type for starting only, as required. No structural alteration necessary in the starter for either type. (4) Large number of contact studs, making any arc-quenching device unnecessary. (5) Slow-moving contact brush operated by deep-cut screw shaft of large diameter. (6) Spring return of contact brush to "off" position by means of large spiral spring on main screw shaft. (7) Speed of screw shaft when released controlled by simple centrifugal governor which absorbs the energy of the revolving parts gradually without introducing static friction; and, therefore, no violent shock when the brush is brought to rest. (8) No sliding contact-bars or flexible connections, as by a special method of arranging the resistance units no connection to the main brush was required. (9) Resistance scientifically graduated for best conditions of starting. (10) No solder used on resistance units, joints made by electric welding.

The diagram (Fig. A) shows the arrangement of the resistance and

Mr. Cowan.

connections of the starter. The resistance units are arranged in two batches, each directly connected to a row of steps, the cursor-brush simply bridging over the two rows of stops, thus avoiding all flexible or sliding connections to it. The lamp shown in the diagram serves the double purpose of a cushioning resistance for the field, and also to indicate when the motor has started, and the speed at which it is running, the candle-power being gradually reduced as the back E.M.F. of the armature balances the E.M.F. of supply. Thus a motor can be started

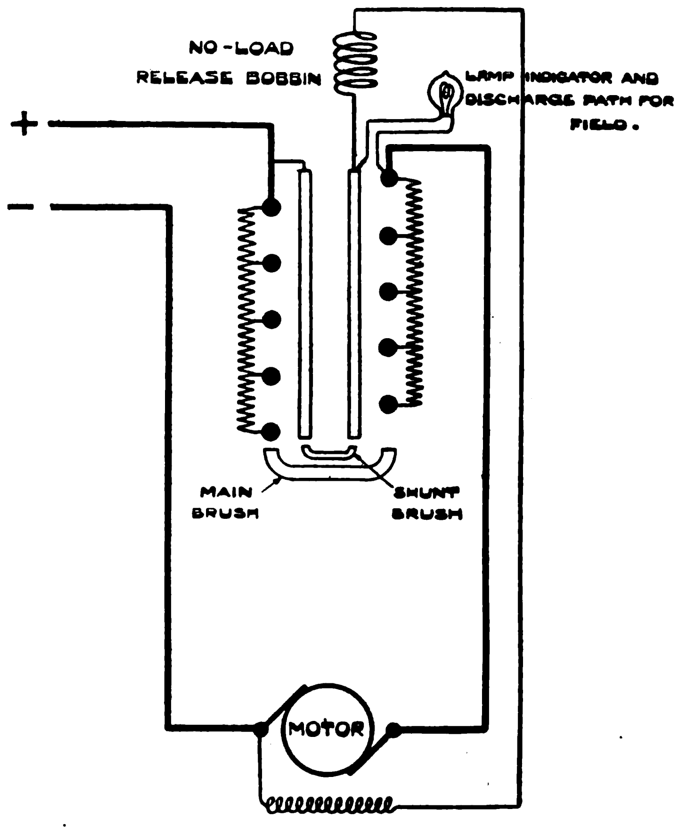


FIG. A.—Diagram of Connections, Cowan's Patent Motor Starter.

at a distance, and its behaviour observed by the brightness of the lamp. The lamp also indicates that all connections are in order, and current on the starter. This lamp is cut out when the motor is running at full speed.

Mr. Woolliscroft.

Mr. J. H. WOOLLISCROFT said that he should like to question and clear up the points and objections raised in the discussion in regard to liquid switches in general, and to the one of his own patented design exhibited at the meeting.

Mr. Vaudrey had remarked that he would not care to start up a motor with the enclosed 5-B.H.P. type of liquid switch shown, as it might boil over. In the first place this switch was only for the purpose of starting up, say at the most 10 times per hour or every six minutes, when at the end of that time it would hardly be warm, but if a controller, or rather a regulator, were required, the size used would be much increased. If a starter were used as a regulator it would get so hot as to boil, and eventually evaporate to dryness, but that would be all, and it would not be burnt out as an ordinary wire starter, used for continuous regulation. There was a relief valve fitted on the case which allowed the small amount of gas made in starting up to escape at once; the hydrogen, being so much lighter than air, escaped during the process of starting up. Although these switches were of an entirely new type, they had been tested under working conditions for some months, and had given the greatest satisfaction. Repeat orders constantly received spoke for themselves, and proved that in practice it had been found a cheap, reliable starter, regulator, or reverser, as the case may be. Mr. Woolliscroft.

In reply to Mr. Cowan, as to the trouble of kick to the motor in short-circuiting when the blade was entirely cut out and the switch short-circuited, the blade area was very liberal, and there was an additional augmenting blade close to the side of the case, and, therefore, when the blades were fully in, that is, as in a wire resistance on the last resistance stop, the resistance between this point and the short-circuiting position was so small that the kick or jump produced by the final short-circuiting of the starter was negligible. Replying to a query put by one of the speakers, he said that for different voltages up to 700 volts the same switch is used, only the density of liquid must be altered to correspond—for the lower pressure, a larger percentage of caustic soda; and for a higher pressure or voltage, a weaker solution. These switches had been supplied up to 60 B.H.P. equipped with overload and minimum releases, and they had not had the slightest complaint in regard to them. An outside current-breaker was not required; they were also non-inductive. Another feature was that, as the blade rotates with a circular movement in switching off, there was, for a second or so, a rapidly diminishing film of liquid leaving the blade tip, and thereby throwing in a very high resistance before opening the circuit. He believed that in this liquid switch the usual troubles of liquid switches had been entirely eliminated.

Mr. Lionel E. Buckell said he thought the importance of starting-switches had, if anything, been underrated by Mr. Bate. Most of those who had had much to do with continuous-current motors would probably consider the starting-switch more likely to give trouble than the commutator. Station engineers in making regulations governing the use of motors did not seem to realise that they were putting obstacles in the way of developing their motor-load with very little advantage to their lighting supply. The suggestion as to rating appeared very valuable, and it was to be hoped that manufacturers would adopt this or some other standard system by which all starting-switches could be compared. There might be a difficulty in the small Mr. Buckell.

Mr. Buckell. wire at the "all-out" end in carrying the full current for half a minute. The absorption type of resistance was an exceedingly troublesome piece of apparatus to repair, and with a starting-switch ease of repair would seem to be more important than the little extra protection afforded. Mr. Bate did not refer to the importance of the material of which the resistance was made, and to the importance of providing sufficient radiating surface. Many of the iron-wired resistances wound on asbestos tubes, in the speaker's experience, gave great trouble due to rusting, and had to be replaced by platinoid wound on slate, which gave no trouble. Mr. Bate's second method of connecting up the switch appeared in practice to give most satisfactory results. Commercial motors seemed to have sufficiently strong insulation on the fields to stand the kick. The strain on the armature due to the torque being applied suddenly was not so serious as the trouble caused by blowing fuses when starting up on a load having heavy inertia in the first method. The overload attachment seemed to be a very doubtful advantage for sizes above 7 or 8 H.P., and a separate magnetic circuit breaker instead of one of the main switches gave much more satisfactory operation, the expense not being very great.

Mr. Brown. Mr. F. BROWN said he did not agree with what Mr. Vaudrey had said as to small motors not requiring starting switches. For he found that the small motors got worse usage than the larger ones, because they were put in less skilled hands, and if they had not a protecting arrangement as to over-load there would be a great deal more trouble than there was.

Mr. Vaudrey. Mr. VAUDREY said that he was referring to the starting of motors of not more than a quarter or half horse-power.

Mr. Brown. Mr. BROWN, proceeding, said he had found liquid resistance-switches very useful for intermittent work, particularly on organ blowing and work of that nature.

Mr. Hunt. Mr. F. O. HUNT said that he could not agree with some of the speakers that the central station engineer was wrong in requiring some sort of limitation on the sudden demand that was to be made on his mains. It would, however, be much better for the manufacturers if the station engineers would arrive at some notion of uniformity as to the extent of this limitation. He also blamed the consulting engineers, who were generally too vague in their statement of the condition to be met. He was in favour of standard rating, but suggested a subdivision of Class I. into full and half-load starters. It was possible to economise if it were specified that the motor would not be required to start up against full load. He advocated a single time test which should give temperature conditions equivalent to the intermittent test proposed in the paper. He thought the character of the test should be based upon the idea of a factor of safety with regard to the time of carrying current, and the factor should be greater in the case of small motors than with large ones, owing to the less skilled handling to which the former are usually subjected.

Mr. Bornand. Mr. VICTOR BORNAND said that the greatest evil was that contractors contented themselves too often with buying light work instead of a sound and reliable apparatus which would always give them satisfac-

tion if they would increase a little more the initial outlay. Armatures were often damaged and burnt out by a badly built motor-starter. Mr. Bornand.

Rating of resistances would avoid many troubles if the specification suggested was followed by every one, and if specially more attention was given to the specification of motor-starters.

The liquid-resistance type of starter was very old indeed, but it could not possibly be compared with metallic starters, which, if they were properly built, did not require any maintenance whatever. To this type of starting gear mentioned, he might perhaps add a similar type of starter, but in which the water was replaced by graphite powder, and it seemed to give very good results.

Of the two different ways of making connections of motor-starters the first, viz., to connect by the shunt magnet through the coil and first contact of the resistance, was that usually adopted. If the second ring contact on the starter was omitted, this mode of connection had the serious drawback that the shunt coil was connected through the starting resistances. This had, first, the effect of raising the speed of the motor about 5 per cent., and, secondly, a dangerous drawback of having the shunt field permanently connected through the starting resistance when the motor is running. Should overheating happen in this resistance (which was composed of wires of different sizes with many junction points and delicate parts) it might get out of order very quickly; and if bad contact through the resistance happens, the armature would simply be a direct short-circuit on the mains.

Referring to the second mode of connection, viz., by connecting the shunt coil to the last contact of the resistance, it presented certain practical advantages, chiefly in not having the field connected through the starting resistance, and that in closing the double pole switch the field of the motor was ready; then by the starting resistance current is gradually supplied to the armature. In stopping the motor no danger was to be expected from the inductive kick of the magnet, as if the double pole switch were opened the remanent magnetism of the no-volt coil would still hold the motor-starter lever in position and the inductive current would discharge through the armature, which would still be running for a few seconds. The kick of the magnet was about four times higher than the voltage of the main, and too much importance might be given to it as it would be a very poor motor if it had a field of so poor insulation that it would not stand the kick of the magnet.

Mr. S. E. Glendenning said that there were now many devices for preventing any mistake being made except by the switch itself. But when full-load current was allowed on the first step, the switch had, in many cases, to be moved very slowly to prevent a much larger rush of current—reminding one of an alternating-current motor. Mr. Glendenning.

Mr. H. F. Hunt said that one or two of the speakers had referred to the drawback of having the shunt connected to the first contact of the resistance on the ground that the field builds up slowly and that therefore the motor cannot start until current has been passing for some time. With large machines it might be so, but in smaller ones the field grew so rapidly that the effect was inappreciable. He recently took some measurements from a 10-H.P. 440-volt ironclad motor having Mr. Hunt.

Mr. Hunt. a normal field current of 1·1 ampere. One second after switching on the shunt, the current was approximately 0·70, in two seconds 0·95, in three 1·08, in four 1·095, and after five seconds 1·1. The field rose to within 5 per cent. of its full value in about two and a half seconds. There was an advantage in connecting both shunt and armature together on the starter.

A good method of testing the starting switch, and one which his firm had adopted, was to connect the starter in series with a special liquid resistance across the full line voltage, and then while one man moved the starting lever over at any required rate, another man kept the current at full-load value—or some fixed amount—by adjusting the liquid resistance. This gave a fair test to the coils at both ends of the starter. Mr. Vaudrey mentioned that for ¼- or ½-H.P. motors no starters were necessary. In such cases an ordinary ½-H.P. shunt-motor would take about ten times its full current at the instant of being switched on to the supply.

A point which some engineers failed to realise was that a motor can always be started from rest sparklessly with a current far in excess of the current which would produce sparking at full speed. This, of course, was due to the reduction of cycles per second in the coils undergoing commutation at the brushes.

In regard to the difficulty of repairing the absorption type of starter, a properly constructed resistance box filled with sand was almost, if not quite, as easy to get at and put right as a set of spirals boxed in with a ventilated cover. Enamel or china rheostats, on the other hand, were almost incapable of repair. Unless a starter were intended for fairly frequent use, the temperature rise would not be very materially different whether it was ventilated or not, since the heat was all generated before any appreciable quantity had time to be radiated.

Mr. Bate. Mr. BATE, replying to the discussion, said most of the speakers seemed to be at variance with him with regard to the connections, but they had not succeeded in convincing him. If for motors smaller even than Mr. Hunt had mentioned, the shunt field rose in half a second, it was not at all in the nature of a blow and did not strain the parts to anything like the same extent as the force applied suddenly with only the self-induction of the armature to retard the current. He quite agreed with Mr. Bornand when he said that if the resistance was left in circuit with the shunt field with so many contacts which were or might be loose, and also in view of the fact that the speed was increased by nearly 5 per cent., it would be very objectionable. But it was a very common thing to short-circuit that resistance through the iron frame of the no-volt magnet coil. For larger motors where the iron did not provide sufficiently good contact an auxiliary contact stud served the purpose. With regard to the full-load current being passed on the first contact, unless the switch was used on central stations mains where there were special rules in force, he thought that for motors of moderate power up to, say, 10 H.P. full-load or even one and a half times full current was allowable, if the motor was properly constructed and had proper sparking limits. In testing motors properly designed from the commutation point of view he had not found any difficulty in

starting up with full-load current. Mr. F. O. Hunt thought the three classes he proposed were not enough. That might be so, but he (Mr. Bate) certainly thought that three classes were better than none. Of course he did not propose that that test should be applied to every motor starter that was made, but that the makers should state that the particular size of starter having already stood such a test would stand it again. Mr. Bate.

Mr. Buckell had pointed out that resistances were generally graded. That was so, but if full-load current were passed through the first contact, and it then had to pass through all the wires, the finest and the coarsest, when the motor speeded up the resistance was cut out, and he took it that no more than full-load current should in the ordinary course of events be put on to any contact or passed through any of the wires. If the starter were tested with the lever on the first contact and full-load current passed through it, with the precaution of the over-load for one test, he thought that would be quite sufficient. Mr. Vaudrey mentioned the American teaser system and the series-parallel motors as being likely to be the future methods of starting large motors. Those methods were very useful indeed where speed-control was necessary; that was a problem quite distinct from starting, and he must say he thought such methods would be too expensive for use in starting only. It certainly would be a great nuisance if they had to make all large motors with two commutators, or provide an auxiliary motor, in order to get another motor running—an auxiliary that only had to be used a few times a day. With regard to the drum-type of starter, of which Mr. Vaudrey spoke rather favourably, he (Mr. Bate) did not think they were suitable for use in ordinary cases as starters, because it was necessary to have the resistance separate from the switch, and that involved the use of many loose connecting wires which were objectionable. You wanted your starter to be self-contained. He was interested in Messrs. Cowan's radiation type of resistance. The sample on the table was in the ordinary way a 30-H.P. motor-starter which was now reduced to a 5-H.P. starter to meet a special specification. That illustrated how money might be squandered if they did not take proper care in getting the specification of the starter properly drawn out for the particular conditions that it had to fulfil.

ORIGINAL COMMUNICATION.

SOME NOTES ON HEAT-RUNS.

By F. W. Carter, M.A., Associate.

Probably the most important test of a piece of electrical apparatus, whether from the point of view of engineer or purchaser, is the service test, or "Heat-run." In this the apparatus is loaded, as nearly as is practicable, to the same extent as it is likely to be when in operation, and is kept so loaded until the final steady condition corresponding to continuous service is attained. If this test develops no indications of a fault, we may conclude that the apparatus will at least stand the service for which it is intended. The usual sign of probable future trouble is high local temperature, and thus the most important part of a heat-run is the determination of temperatures of various parts of the apparatus.

Although such a test requires no high powers of observation, there is, nevertheless, great difficulty in obtaining consistent results on account of the number of conditions—some of them quite indeterminate—affecting the results. Where it is merely a question of discovering whether a machine of known type, and so of approximately known service rating, has any abnormal features, great accuracy is not necessary, for outside conditions will not usually be sufficiently active to affect general conclusions. But where service tests on a perfectly normal machine are to be made the basis of future developments, or to be employed in predicting the performance of the machine in any class of service that may arise, it is of the utmost importance to determine to what extent the several tests are affected by particular circumstances, and, where possible, to allow for these circumstances.

The author, having had occasion to work on a class of service test which requires all the accuracy that can be attained, whilst being subject to many disturbing influences, has developed certain methods of treatment which it will probably be well to place on record for the benefit of those engaged on similar work, since the same methods apply, to a greater or less degree, to heat-runs generally. The tests referred to are service tests of railway motors—a class of work which has been highly developed by the General Electric Co., being carried out on their experimental railroad at Schenectady.

These tests, being made out of doors, are particularly liable to be affected by atmospheric influences, some of which—such as wind and damp—produce effects that can only be estimated, and are best avoided when possible by a proper choice of the day of test. Again, the source of power is likely to vary, especially if it carries other load besides the running of the test. Then, unless some form of automatically accelerating controller is used, a change of motorman will probably alter the accelerating current. These and other things can be varied much faster than the temperature

which depends on them can follow. The ideal test would determine the temperatures corresponding to a steady and constant set of conditions; the actual test determines the temperatures corresponding to a set of variable conditions, and our present business is to show how to find the set of constant conditions which would be competent to produce the same heating as the actual variable conditions do produce.

In order to fully appreciate the importance of the following calculations, it is necessary to understand the object and use of the tests. The method used in working them up is indicated in a recent paper by A. H. Armstrong,* and need not be given at length here. Briefly, we determine the final temperature rise of both armature and field magnet coils, corresponding to continuous operation on a definite schedule with a definite weight of car or train, maintaining, as nearly as practicable, uniform voltage and accelerating current. Resistances of armature and field magnet coils, and all the temperatures that can conveniently be obtained are taken hourly, until practical constancy is reached. A number of records of current and voltage are made during the run by means of railway recording instruments, especially designed for such work, and from these we deduce the mean losses in iron and copper of both armature and field magnet. From a series of such runs the thermal characteristic curves of the motor are drawn. These are plotted between ratio of armature loss to field magnet loss as abscissa, and temperature rise per mean watt loss as ordinate—there being one curve for the armature and another for the field. If now it is proposed to use the type of motor for a certain service the losses in armature and field magnet incident to the service are computed. Then, from the ratio of distribution of the losses, the temperature rise per watt loss is found from the thermal characteristic curves, whence the actual temperature rise in armature and field—assumed proportional to the loss. Thus is predetermined whether the motor is competent to undertake the service in question. It is obvious that these thermal characteristic curves are of the utmost importance to the engineer. The tests required to obtain them are expensive, and warrant considerable pains being taken to render the results as reliable as possible.

Of disturbing influences, indeterminate ones, such as wind and rain, are avoided as far as possible by always electing to run on a still and dry day. The air temperature, however, will usually vary during the run, often dropping 5 to 10° C. as evening approaches. The motor only follows this variation very slowly, and it becomes necessary to determine an equivalent air temperature, such that the excess of the motor temperature above it is the true rise corresponding to the losses.

The voltage again may vary considerably during the day—though it is naturally more satisfactory if it can be kept constant—and if it does vary, we have to find the equivalent voltage that would lead to the observed final temperatures. Then, too, the time occupied in taking resistances and temperatures is likely to vary from hour to hour, or an accident may stop regular running for a period, and so we have to determine the equivalent value for the time so lost per hour

* "A Study of the Heating of Railway Motors," by A. H. Armstrong, *Trans. Amer. Inst. Elec. Engs.*, vol. xix.

that would lead to the temperatures actually observed. These are the chief of the variable factors affecting runs of this kind, but the methods employed in dealing with them will be found generally applicable to any such variable factors. We may note that the equivalents so found differ from the simple mean of the readings, and may differ considerably from it. If, for instance, the voltage is low for an hour near the end of the run, the effect on the final temperature will be considerably greater than if it were equally low for an hour some time before the end. In finding the equivalent, therefore, we have to give the greater weight to a reading the nearer it is to the end of the run, and we may describe our present problem as that of determining the weight to be given to a reading according to its position in the run.

The nature of the test, however, does not permit of greater accuracy than is obtained by taking the mean of the readings during an hour as the true value for that hour; that is, we divide the time of running into hours, and give equal weight to all readings in any particular hour.

If θ is the average temperature of the machine at time t, and T the air temperature, w the watts lost, or converted into heat in the machine, and R the watts radiated and convected from it, then $w - \mathrm{R}$ is the rate at which the amount of heat in the machine is accumulating, varying as the rate of rise of temperature, say, $= \mathrm{K}\frac{d\theta}{dt}$.

Now, R varies as the excess of the machine temperature over that of the air outside, say, $\mathrm{R} = k(\theta - \mathrm{T})$. Hence

$$\mathrm{K}\frac{d\theta}{dt} = w - k(\theta - \mathrm{T}),$$

$$\text{or} \quad \frac{d\theta}{dt} + p\theta = p\mathrm{T} + p\frac{w}{k}, \quad \ldots\ldots \quad (1)$$

$$\text{writing } \frac{k}{\mathrm{K}} = p.$$

Now, if T and w were constant ($= \mathrm{T}'$ and w' say), this would integrate to—

$$\left.\begin{aligned} \theta &= \mathrm{T}' + \frac{w'}{k} - \left(\mathrm{T}' + \frac{w'}{k} - \theta'\right)\epsilon^{-pt} \\ \text{or} \quad \theta &= \theta'\epsilon^{-pt} + \left(\mathrm{T}' + \frac{w'}{k}\right)\left(1 - \epsilon^{-pt}\right) \end{aligned}\right\} \quad \ldots\ldots \quad (2)$$

where θ' is the temperature of the machine when the regular load is put on (*i.e.*, when $t = o$). The term involving ϵ^{-pt} becomes smaller as t becomes larger, and its becoming practically negligible is the condition that a constant temperature is attained, and the heat-run may be brought to a close. We can shorten the run accordingly by making the coefficient of ϵ^{-pt} small, that is, by heating the machine (by means of an overload, say) until its temperature nearly reaches the final steady value corresponding to the regular load. [Note that with different

machines the minimum length of the heat-run varies as $\frac{1}{p}$.] Thus, the final temperature when the term in ϵ^{-pt} has become negligible is

$$\theta = T' + \frac{w'}{k} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

When, however, T and w are functions of t, the integral of 1 becomes

$$\theta = \theta' \epsilon^{-pt} + p \epsilon^{-pt} \int_0^t T \epsilon^{pt} dt + p \epsilon^{-pt} \int_0^t \frac{w}{k} \epsilon^{pt} dt \quad . \quad . \quad . \quad (4)$$

Thus, if we take T′ and w' as equivalent values, competent to produce the same final temperatures as are actually reached, we get by equating the values of θ from equations (2) and (4)—

$$\left(T' + \frac{w'}{k}\right)\left(1 - \epsilon^{-pt}\right) = p \epsilon^{-pt} \int_0^t T \epsilon^{pt} dt$$
$$+ p \epsilon^{-pt} \int_0^t \frac{w}{k} \epsilon^{pt} dt,$$

whence—

$$T' (1 - \epsilon^{-pt}) = p \epsilon^{-pt} \int_0^t T \epsilon^{pt} dt \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

$$w' (1 - \epsilon^{-pt}) = p \epsilon^{-pt} \int_0^t w \epsilon^{pt} dt \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

In these equations time is measured from the beginning of the regular run onwards towards the end. We shall find it more convenient for our purpose, however, if we measure time from the end of the run towards the beginning. Equations (5) and (6) then become—

$$T' (1 - \epsilon^{-pt}) = p \int_0^t T \epsilon^{-pt} dt \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

$$w' (1 - \epsilon^{-pt}) = p \int_0^t w \epsilon^{-pt} dt \quad . \quad . \quad . \quad . \quad . \quad . \quad (8)$$

The task before us is now that of evaluating these integrals. We note that equations (7) and (8) are of similar form, so that the same method can be used to determine either the equivalent air temperature or the equivalent motor loss. Conducting the argument in the language of losses, let w_1 be the mean loss during the last hour of the run; w_2 that during the hour preceding the last; w_3 that during the next preceding, and so on, and assume that during any particular hour, or other suitable unit of time, the loss remains uniform at its mean value. Then—

$$p\int_0^t w e^{-pt}\,dt = p\,w_1\int_0^1 e^{-pt}\,dt + p\,w_2\int_1^2 e^{-pt}\,dt + p\,w_3\int_2^3 e^{-pt}\,dt + \dots$$
$$+\,p\,w_n\int_{n-1}^{n} e^{-pt}\,dt$$
$$= w_1(1-e^{-p}) + w_2(e^{-p}-e^{-2p}) + w_3(e^{-2p}-e^{-3p}) + \dots$$
$$+\,w_n(e^{-\overline{n-1}p}-e^{-np})$$

Thus writing $q = e^{-p}$ we get—

$$w'(1-q^n) = w_1 + q(w_2-w_1) + q^2(w_3-w_2) + \dots$$
$$+\,q^{n-1}(w_n-w_{n-1}) - q^n w_n \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (9)$$

This gives the equivalent loss in terms of the readings and the quantity q, which depends on the motor, and of which more will be said hereafter.

Suppose now the variation in loss is due to varying voltage. If this variation is not excessively large, we may, without great error, assume that the change in watts is proportional to the change in voltage. This is the same as supposing that the watt-volt curve practically coincides with its tangent in the neighbourhood of the point where we are working. Thus, writing $w = a\,V + \beta$, we get from equation (9)—

$$(a\,V^1 + \beta)(1-q^n) = a\,V_1 + \beta + q\,a(V_2-V_1) + q^2 a(V_3-V_2) + \dots$$
$$q^{n-1}a(V_n-V_{n-1}) - q^n(a\,V_n+\beta)$$

or—

$$V^1(1-q^n) = V_1 + q(V_2-V_1) + q^2(V_3-V_2) + \dots$$
$$+\,q^{n-1}(V_n-V_{n-1}) - q^n V_n \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (10)$$

the same form as equation (9).

Suppose again that the variation in loss is due to variation in time of stoppage, for taking temperature or other cause. The mean loss is proportional to the time the regular schedule is being made, or to $60 - t$, where the time lost is t minutes per hour. Hence from equation (9)—

$$(60-t')(1-q^n) = 60 - t_1 + q(t_1-t_2) + q^2(t_2-t_3) + \dots$$
$$+\,q^{n-1}(t_{n-1}-t_n) - q^n(60-t_n)$$

or—

$$t'(1-q^n) = t_1 + q(t_2-t_1) + q^2(t_3-t_2) + \dots$$
$$+\,q^{n-1}(t_n-t_{n-1}) - q^n t_n. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (11)$$

again the same form as equation (9).

Having in this way obtained equivalent values of the several factors affecting the losses, we use these in computing the losses to which the observed temperatures correspond.

The air temperatures are read hourly, so that if the readings are $T_0, T_1, T_2, \dots T_n$ (beginning from the end of the run), the mean temperatures for the several hours are $\frac{T_0+T_1}{2}$, $\frac{T_1+T_2}{2}$, etc. Thus the equivalent air temperature is given by—

$$T'(1-q^n) = \frac{T_0+T_1}{2} + q\left(\frac{T_1+T_2}{2} - \frac{T_0+T_1}{2}\right)$$
$$+ q^2\left(\frac{T_3+T_2}{2} - \frac{T_2+T_1}{2}\right) + \ldots q^n \frac{T_{n-1}+T_n}{2}$$

$$= \tfrac{1}{2}\left\{T_0 + T_1 + q(T_2-T_0) + q^2(T_3-T_1) + \ldots\right.$$
$$\left. + q^{n-1}(T_n - T_{n-2}) - q^n(T_{n-1}+T_n)\right\} \quad . \; . \; . \; . \; . \; . \; (12)$$

This is the air temperature that should be used in calculating temperature rises.

Although I consider equation (12) sufficiently accurate to suit the requirements of heat-runs, I will give a more accurate solution of the same problem, partly because an exceptional case may call for greater accuracy, but principally because the question of equivalent air temperature is not connected exclusively with heat-runs, but may arise in laboratory tests, capable of high accuracy. While in the above we have assumed that the temperature in the interval of time between two readings remains constant at the mean of the readings, we will now suppose that the temperature-time curve is composed of straight lines joining the readings—which assumed curve is never likely to be far from the true temperature-time curve. We will suppose, as before, that the readings are taken at equal intervals of time, and will take the common interval as our unit. Thus, referring to equation (7), suppose that the air temperature between times o and 1 is given by

$$T = T_0 + (T_1 - T_0)\,t\,;$$

between times 1 and 2 by

$$T = T_1 + (T_2 - T_1)(t-1),$$

and so on. Now

$$p\int_0^1 [T_0 + (T_1 - T_0)t]\,e^{-pt}\,dt = T_0(1-e^{-p}) + (T_1-T_0)\left(\frac{1-e^{-p}}{p} - e^{-p}\right)$$
$$= T_0 + \frac{T_1-T_0}{p} - \left(T_1 + \frac{T_1-T_0}{p}\right)e^{-p}$$

$$p\int_1^2 [T_1 + (T_2-T_1)(t-1)]\,e^{-pt}\,dt = \left(T_1 + \frac{T_2-T_1}{p}\right)e^{-p}$$
$$- \left(T_2 + \frac{T_2-T_1}{p}\right)e^{-2p}$$

. . . .

$$\therefore\; T'(1-e^{-np}) = T_0 - T_n e^{-np} + \frac{1}{p}\Big\{(T_1-T_0) + (T_2+T_0-2T_1)e^{-p}$$
$$+ (T_3+T_1-2T_2)e^{-2p} + \ldots + (T_n+T_{n-2}-2T_{n-1})e^{-(n-1)p}$$
$$- (T_n - T_{n-1})e^{-np}\Big\}$$

or—

$$T'(1 - q^n) = T_0 - T_n q^n + \frac{1}{p}\Big\{T_1 - T_0 + (T_2 + T_0 - 2T_1)\,q + (T_3 + T_1 - 2T_2)\,q^2 + \ldots + (T_n + T_{n-2} - 2T_{n-1})\,q^{n-1} - (T_n - T_{n-1})\,q^n\Big\} \quad \ldots \ldots \quad (13)$$

The calculation of T′ from this equation is not difficult if systematically performed. The arrangement on page 1111 enables the equivalent air temperature to be found for every hour during the run.

It will be found that a small error in the value of q will have very little effect on the results; nevertheless it is such a frequently recurring quantity that we naturally seek to determine it as accurately as possible. If a number of runs are made on a particular type of motor, we can usually find one in which—for part of the run at any rate—there has been a considerable rise or fall in temperature, while circumstances affecting the final temperature have remained approximately constant. To such a run we can apply equation 2 to determine q or ϵ^{-p}. Thus, let θ_1, θ_2, and θ_3 be consecutive readings of temperature, corresponding to times t, $t + 1$, and $t + 2$ (the unit of time being the common interval between readings), then—

$$\theta_1 = T' + \frac{w'}{k} - \left(T' + \frac{w'}{k} - \theta'\right) q^t$$

$$\theta_2 = T' + \frac{w'}{k} - \left(T' + \frac{w'}{k} - \theta'\right) q^{t+1}$$

$$\theta_3 = T' + \frac{w'}{k} - \left(T' + \frac{w'}{k} - \theta'\right) q^{t+2}$$

$$\therefore \quad \frac{\theta_3 - \theta_2}{\theta_2 - \theta_1} = \frac{\left(T' + \frac{w'}{k} - \theta'\right) q^{t+1}(1 - q)}{\left(T' + \frac{w'}{k} - \theta'\right) q^t (1 - q)} = q \quad . \; . \; (14)$$

If the conditions remain constant for four or six units of time, we shall obtain greater differences in temperature, and therefore greater accuracy, if we take the readings θ_1, θ_2, and θ_3, two or three units of time apart. If they are separated by two units, equation 14 gives q^2 instead of q, and if by three units q^3, and so on.

Again—

$$q = \epsilon^{-p}$$

$$\therefore \; p = \log_e \frac{1}{q} = 2{\cdot}3 \log_{10} \frac{1}{q}$$

Again, remembering that the final temperature (θ) is $\theta = T' + \frac{w'}{k}$, we get—

$$\frac{\theta - \theta_1}{\theta - \theta_2} = \frac{\theta - \theta_2}{\theta - \theta_3} = \frac{1}{q}$$

giving—

$$\theta = \theta_3 + \frac{(\theta_3 - \theta_2)^2}{2\,\theta_2 - \theta_1 - \theta_3}.$$

	T_0	T_1	T_2	...	...	T_{n-1}	T_n
q q^2 q^3 q^{n-1} q^n	$T_1 - T_0 (= \tau_1)$ $q\ (\tau_2 - \tau_1)$ $q^2 (\tau_3 - \tau_2)$ $q^3 (\tau_4 - \tau_3)$ ... ... $q^{n-1} (\tau_n - \tau_{n-1})$ $- q^n \tau_n$	$T_2 - T_1 (= \tau_2)$ $q\ (\tau_3 - \tau_2)$ $q^2 (\tau_4 - \tau_3)$ $q^3 (\tau_5 - \tau_4)$ ... ... $- q^{n-1} \tau_n$	$T_3 - T_2 (= \tau_3)$ $q\ (\tau_4 - \tau_3)$ $q^2 (\tau_5 - \tau_4)$	... ...	... $q\ (\tau_n - \tau_{n-1})$ $- q^2 \tau_n$	$T_n - T_{n-1} (= \tau_n)$ $- q\ \tau_n$	T_n $q\ T_n$ $q^2 T_n$ $q^3 T_n$ $q^{n-1} T_n$ $q^n T_n$
	←	The Algebraic sum of the several columns					
	←	The same divided by p			→		
	$T_0 - T_n q^n$	$T_1 - T_n q^{n-1}$	$T_2 - T_n q^{n-2}$	...	...	$T_{n-1} - T_n q$	T_n
		The sum of the last two lines =					
	$T'_0 (1 - q^n)$	$T'_1 (1 - q^{n-1})$	$T'_2 (1 - q^{n-2})$	...	...	$T'_{n-1} (1 - q)$	T'

This gives the final temperature in terms of the readings, and is often useful when the run has not been continued quite long enough to reach a steady condition. Of course it should not be employed when the temperatures are far from constant, unless outside conditions are far steadier than they ever are in practice.

It now remains to give a few examples illustrating the above methods. A certain railway motor gave, as the mean temperature of the field-coils, the following readings at hourly intervals:—

$$57{\cdot}5^\circ,\ 64^\circ,\ 68{\cdot}2^\circ,\ 71^\circ \text{ C.};$$

thus from the first three—

$$q = \frac{4{\cdot}2}{6{\cdot}5} = {\cdot}645;$$

and from the last three—

$$q = \frac{2{\cdot}8}{4{\cdot}2} = {\cdot}665.$$

Thus we may take $q = {\cdot}65$, leading to $p = {\cdot}43$. Had the readings been taken half-hourly, we should have had—

$$q = \sqrt{{\cdot}65},\ p = \frac{1}{2} \times {\cdot}43.$$

The final temperature indicated by the above is—

$$\theta = 71 + \frac{2{\cdot}8^2}{1{\cdot}4} = 76{\cdot}6^\circ \text{ C.}$$

In one of the runs on these motors, the mean voltages found for the last six hours of the run were as follows:—

526, 535, 518, 492, 488, 506.

Thus, from equation (10)—

$$V'(1 - {\cdot}65^6) = 506 - 18 \times {\cdot}65 + 4 \times {\cdot}65^2 + 26 \times {\cdot}65^3 + 17 \times {\cdot}65^4 - 9 \times {\cdot}65^5 - 526 \times {\cdot}65^6,$$

or

$$V' = 503 \text{ volts.}$$

The time that the regular schedule was stopped for taking temperatures was, for the several hours, 6 min., 4 min., 4 min., 8 min., 5 min., 6 min., 4 min. As these intervals of time occur at the ends of the hours, we shall divide each equally between the hours that they end and begin, and thus we get the series, 5 min., 4 min., 6 min., 6·5 min., 5·5 min., 5 min. Thus the equivalent time lost is from equation (11)—

$$t' = 5{\cdot}4 \text{ minutes.}$$

The readings of air temperature were respectively, 27·5°, 29°, 32°, 30·5° *, 29°, 27°, 20·5° C.

* Reading omitted and supplied by interpolation.

Thus, from equation (12)—

$$T'(1 - \cdot65^6) = \frac{1}{2}\Big\{20\cdot5 + 27 + 8\cdot5 \times \cdot65 + 3\cdot5 \times \cdot65^2 + 3 \times \cdot65^3$$
$$- 1\cdot5 \times \cdot65^4 - 4\cdot5 \times \cdot65^5 - (27\cdot5 + 29) \times \cdot65^6\Big\}$$

or

$$T' = 27\cdot2^\circ \text{ C.}$$

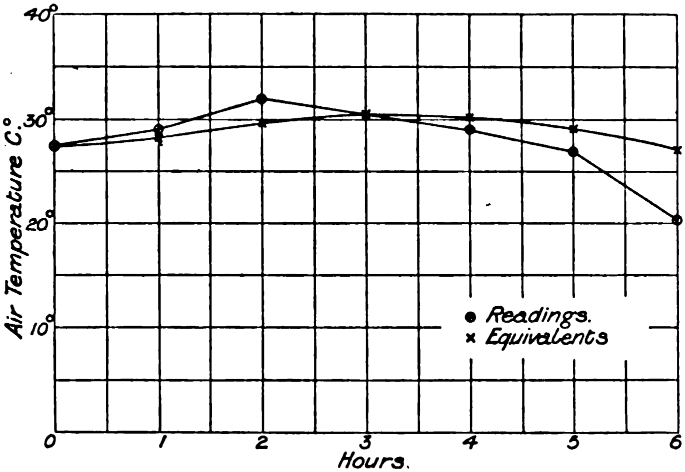


FIG. 1.

Calculating T′ for each hour from equation 13, according to the method given in the table on page 1111, we get the following:—

	20·5	27	29	30·5	32	29	27·5
	6·5	2	1·5	1·5	— 3	—1·5	27·5
·65	—2·92	— ·32	0	—2·92	·98	·98	17·88
·423	— ·21	0	—1·90	·64	·64		11·65
·275	0	—1·24	·42	·42			7·58
·178	— ·81	·27	·27				4·94
·116	·18	·18					3·21
·075	·12						2·09
	2·86	·89	·29	— ·36	—1·38	— ·52	
$\div \cdot43 =$	6·64	2·07	·67	— ·84	—3·21	—1·21	
$T_0 - q'' T_n$	18·41	23·79	24·06	22·92	20·35	11·12	27·5
	25·05	25·86	24·73	22·08	17·14	9·91	
T′ =	27·1	29·2	30·1	30·5	29·7	28·4	27·5

In Fig. 1 the readings of air temperature and the calculated equivalent temperature are plotted, and the curves show how sluggish such a machine may be in responding to a change of outside conditions.

Thus, we see how the indefiniteness in the results due to varying outside conditions can, to a very great extent, be removed by keeping a careful record of outside conditions, and computing from the record certain fictitious constant conditions, equivalent to the actual conditions in thermal effect. By such means this very troublesome type of test can be made to yield results whose consistency is in keeping with their importance, and that with comparatively small labour.

At a Special General Meeting of Members, Associate Members, and Associates duly convened and held at the Offices of the Institution, 92, Victoria Street, Westminster, on Friday, July 31, 1903—Mr. ROBERT K. GRAY in the chair.

The Secretary read the notice convening the Meeting.

The President explained that the Council considered it would be unwise not to take advantage of an opportunity which offered to acquire certain property in Tothill Street, although they did not propose to proceed immediately with the construction of the building.*

He therefore proposed—

> "That the purchase of the property in Tothill Street at the price of £16,500 be sanctioned and approved, and that the sale of such of the investments of the Institution as the Council may select as may be necessary to provide the purchase money be sanctioned."

The resolution was seconded by Mr. W. M. Mordey, and was then put to the meeting and carried.

The President having declared the resolution carried, proposed a vote of thanks to the Building Committee, which was also carried.

* The property, which is in part freehold, in part long leasehold (over 900 years), is at present tenanted and yields a return for the invested capital

The Thirty-first Annual General Meeting of the Institution was held at the Offices of the Institution, 92, Victoria Street, S. W., on Thursday afternoon, May 28th, 1903, at 5 p.m.—Mr. ROBERT KAYE GRAY, President, in the chair.

The Secretary read the notice convening the Meeting.

The minutes of the Ordinary General Meeting of May 12th were, by permission of the meeting, taken as read, and signed by the President.

The names of new candidates for election, after having been suspended, previous to the meeting, in the Library, were taken as read, and the President stated that, the present meeting being the last of the Session, the candidates would, as usual, be balloted for that afternoon.

The following list of transfers was published as having been approved by the Council :—

From the class of Associate Members to that of Members—

Arthur Pemberton Wood.

From the class of Associates to that of Members—

Henry Cuthbert Hall.

From the class of Associates to that of Associate Members—

Jas. Lowry Chambers.
Sidney Crouch.
Wm. Densham.
Sorab Frommurze.
Philip Hunter-Brown.
Christopher Holden.
Victor Martos.
Evers Musgrave.
Geo. Addison Williams.
Herbert Wm. Wilson.

Messrs. W. McGregor and E. O. Walker were appointed scrutineers of the ballot for new members.

Donations were announced as having been received since the last meeting, to the *Library* from Messrs. J. J. Fahie, and Rentell & Co.; to the *Building Fund* from Messrs. W. R. Rawlings, R. Rigg, Captain Saltren-Willett; and to the *Benevolent Fund* from Captain Saltren-Willett, to all of whom the thanks of the meeting were unanimously accorded.

The PRESIDENT: The next matter before us is the Annual Report of the Council. I believe that all those present have the Report in their hands, and I think I should meet the convenience of every one by asking you to take the Report as read. If any one objects to that proceeding I shall be very glad to do otherwise, but it is a lengthy document. Is it your pleasure that it should be taken as read?

The motion was carried *nem. con.*

REPORT OF THE COUNCIL PRESENTED AT THE ANNUAL GENERAL MEETING OF MAY 28, 1903.

The Council has the pleasure of presenting its Annual Report upon the work of the Institution.

THE ARTICLES OF ASSOCIATION.

The rapidly extending scope and work of the Institution had for some years past been attended by an increase in expenditure greater in proportion than the growth of revenue, and the Council considered that to place the Institution finances upon a sound basis, some alteration in the rates of subscription would have to be faced. A letter was therefore sent to the members of all classes explaining the proposals of the Council, and freely inviting expressions of opinion.

The Council was gratified at the response to their invitation. The replies were analysed, and all the views expressed in them carefully considered, with the result that the original proposals were modified in some respects. The final proposals to alter the subscriptions were laid before the necessary Special General Meetings of Members on the 4th and 19th of December, 1902. The opportunity was taken to put forward certain alterations in others of the Articles of Association. Yet further proposals that were not in shape at the time of these meetings, which had of necessity to be held before the commencement of the new subscription year, were laid before Special General Meetings of Members on the 26th of February and the 17th of March, 1903.

The proposed alterations were duly made, and now appear in the Journal of the Institution. Apart from the alterations of subscriptions the following changes among others have been effected :—

The raising of the normal age for admission to the class of Members (M.I.E.E.) from twenty-five to thirty ;

The suppression of the special clause under which Associates on the Register in 1898 could apply for transfer to the class of Associate Members without being proposed and supported by Members of the Institution ;

The cessation of entries to the class of Foreign Members, a class which was in some sense redundant, since foreigners, equally with British subjects, are eligible for admission to any class for which they may be, professionally and otherwise, qualified ;

The increase in the upper age limit, from twenty-two to twenty-six, of Students who have been three years or over attached to the Institution, so that qualified Students pass direct to the class of Associate Members, whilst a sub-class of Senior Students has been created with a subscription intermediate between that of a Junior Student and that of an Associate.;

The conferment on the Council of power, to be used at their discretion, to remove from the Register the name of any convicted felon or, if need be, of an adjudicated bankrupt ;

The restriction of the field of selection of a President to past and present Vice-Presidents, and of that of a Vice-President to past and present Members of Council ; and the retirement of two Vice-Presidents

(instead of one) annually, in order to increase the number of candidates eligible for the office of President; and

The extension to Associate Members of the privilege of attending and voting at meetings called to alter the Articles of Association.

The Presidency.

During the Session, the arrangement for the entertainment of the Delegates to the International Telegraph Conference, and the desire on the part of Mr. Swinburne that these arrangements should, from the outset, be made by a direct representative of some branch of Telegraphy, led to his placing his resignation of office in the hands of the Council two months earlier than he would ordinarily have retired. The Council reluctantly accepted his decision, and expressed in the following Resolution its feelings of gratitude for the good work that he had done for the Institution while President, and its regret that his term of office should have been shortened :—

"Resolved that the Council, in placing on record its high appreciation of Mr. Swinburne's generosity in vacating the Presidential chair before his year of office had expired in order to assist the Council in making adequate arrangements for the reception of the delegates to the approaching International Telegraph Conference, desires hereby to express its cordial thanks to Mr. Swinburne for the admirable way in which he has conducted the affairs of the Institution during his Presidency, and for the unfailing tact and courtesy which he has shown throughout."

Mr. Robert Kaye Gray was unanimously elected President in place of Mr. Swinburne.

The Treasurership.

It was with great regret that the Council, in October, received from Professor Ayrton his resignation of the office of Treasurer, as foreshadowed by him at the last Annual General Meeting. The Council felt that they were losing the services of one who, unsparing of himself, had given unstinted help to the Institution for many years, and they regretted his resignation the more because it was largely due to ill-health. They are glad, however, to feel that his personal interest in the work of the Institution is unabated.

In his place the Council elected Mr. Robert Hammond, who for some years had been an active and valued member of the Finance Committee.

Local Sections.

During the year a Local Section has been formed with its centre at Leeds, embracing the whole of Yorkshire with the exception of Middlesbrough and the Cleveland District, which were already included in the area of the Newcastle Local Section.

The good work of the older Local Sections has gone on steadily, and the Council offers its warmest congratulations to the several Com-

mittees and their respective Hon. Secretaries for the able management of their affairs.

Elections and Transfers.

During the period since the last Annual General Meeting there have been elected 35 Members, 135 Associate Members, 155 Associates, and 229 Students, making a total of 554. 58 Candidates have also been approved for ballot to-night.

Twenty-three Associate Members, 2 Foreign Members, and 14 Associates have been transferred to the class of Members; 213 Associates and 3 Students have been transferred to the class of Associate Members, and 61 Students to the class of Associates.

Deaths and Resignations.

The Council mourns the loss to the Institution by death of 1 *Past President*, Sir Frederick A. Abel, Bart; 8 *Members*, F. Bolton, E. T. Carter, F. T. B. Daniell, Dr. J. H. Gladstone, H. T. Goodenough, A. Graves, G. R. Mockridge, S. H. Short, C. F. Tietgen, J. Wimshurst; 6 *Associate Members*, F. Bathurst, B. A. Giuseppi, L. W. Heath, M. G. A. Humphrey-Moore, J. Seccombe, C. G. Vines; 8 *Associates*, G. H. Bailey, J. Beattie, A. Dennis, W. H. Druce, H. D. Fearon, R. Gibson, F. B. Hobler, G. Ireland, A. D. Manlove; and 1 *Student*, J. Walker-Hanna.

Fourteen Members, 3 Associate Members, 16 Foreign Members, 52 Associates, and 12 Students have resigned since the date of the last Report.

Trustee.

By the death of Sir Frederick Abel, the Institution has lost one of its oldest Trustees. In his place Mr. James Swinburne has been appointed a Trustee of the Institution, and also of the Willans Fund.

Papers.

In addition to the President's Inaugural Address, the following papers, read at Ordinary and Extraordinary General Meetings, will be found in Volume 32 of the Journal :—

Date. 1902.	Title of Paper.	Name of Author.
Nov. 27.—	"On Electrons"	Sir O. Lodge, F.R.S., Vice-President.
Dec. 11.—	"Photometry of Electric Lamps"	Dr. J. A. Fleming, F.R.S.
1903.		
Jan. 8.—	"Notes on Recent Electrical Design"	W. B. Esson, Member.
" 8.—	"Notes on the Manufacture of Large Dynamos and Motors"	E. K. Scott, Member.
" 22.—	"Notes on the Metrical System of Weights and Measures"	A. Siemens, Past President.
Feb. 12.—	"The Nernst Lamp"	J. Stöttner, Member.
Mar. 26.—	"Distribution Losses in Electric Supply Systems"	A. D. Constable, Associate Member; E. Fawssett, Associate.

Date. 1903.	Title of Paper.	Name of Author.
April 30.—	"Divided Multiple Switchboards, an Efficient Telephone System for the World's Capitals"	W. Aitken, Member.
May 7.—	"Applications of Electricity in Engineering and Shipbuilding Works"	A. D. Williamson, Member.
„ 7.—	Electric Driving in Machine Shops"	A. B. Chatwood, Member.

And the following papers, selected from those read at Local Section Meetings, have been (up to the present) accepted for publication :—

Birmingham Local Section.

Date.	Title.	Author.
1902.		
Mar. 19.—	"Tests on the Nernst Lamp"	R. H. Hulse.
Dec. 10.—	Chairman's Inaugural Address	H. Lea, Member.
1903.		
Feb. 25.—	"Network Tests and Station Earthing"	A. M. Taylor, Member.
April 29.—	"Notes on Motor Starting Switches"	A. H. Bate, Associate Member.

Dublin Local Section.

May 29.—	"Lighting and Driving of Textile Mills by Electricity"	M. Osborne, Associate Member.
Nov. 21.—	"A Hydro-Electric Phenomenon"	F. Gill, Member.

Glasgow Local Section.

April 8.—	"Notes on the Testing of Tramway Motors, and an Investigation into their Characteristic Properties"	M. B. Field, Member.
Nov. 11.—	"The Design of Continuous Current Dynamos"	H. A. Mavor, Member.
1903.		
Feb. 10.—	"A Study of the Phenomenon of Resonance in Electric Circuits by the Aid of Oscillograms"	M. B. Field, Member.*

Manchester Local Section.

1902.		
Nov. 25.—	"High Temperature Electro-Chemistry: Notes on Experimental and Technical Electric Furnaces"	R. S. Hutton, Associate; and J. E. Petavel, Associate Member.
1903.		
Jan. 20.—	Chairman's Inaugural Address	H. A. Earle, Member.
Mar. 3.—	"The Arrangement and Control of Long Distance Transmission Lines"	E. W. Cowan and L. Andrews, Members.
April 7.—	"Comparison between Steam and Electrically Driven Auxiliary Plant in Central Stations"	C. D. Taite, Member, and R. S. Downe, Associate Member.
„ 21st.—	"The Carriage of Goods on Electric Tramways"	A. H. Gibbings, Member.

Leeds Local Section.

Feb. 19.—	Chairman's Inaugural Address	H. Dickinson, Member.
„ 19.—	"Motive Power Supply from Central Stations"	R. A. Chattock, Member
Mar. 19.—	"Electricity Supply for Small Towns and Villages"	A. B. Mountain, Member.

* This paper was afterwards read in Abstract, and discussed with Messrs. Constable and Fawssett's paper, at an Ordinary General Meeting of the Institution in London.

Newcastle Local Section.

Date.	Title.	Author.
1902.		
Feb. 17.—	"The Equipment of a Modern Telephone Exchange"	F. A. S. Wormull, Associate.
Nov. 17.—	Chairman's Inaugural Address	J. H. Holmes, Member.
Dec. 1.—	"Experiments on Synchronous Converters"	Dr. W. M. Thornton, Member.
„ 15.—	"Railway Block Signalling"	J Pigg, Associate Member.
1903.		
Jan. 19.—	"Methods of Supporting and Protecting Inside Conductors"	O. L. Falconar, Associate Member.
Feb. 16.—	"Some Notes on Continental Power-House Equipment"	H. L. Riseley, Associate Member

The Institution is again indebted to the Institution of Civil Engineers, and to the Society of Arts for the permission to hold the General Meetings of the Institution in their rooms.

Publications of the Institution.

The papers above referred to have been, or will be, printed in the Journal of the Institution, and, in addition, the following Original Communications have been approved for publication :—

"Notes on the Teaching of Electrical Engineering in the Technical High Schools of Charlottenburg and Darmstadt"	D. K. Morris, Associate Member.
"Mean Horizontal and Mean Spherical Candle-Power	A. Russell, Member.

Science Abstracts.

The publication of *Science Abstracts* in collaboration with the Physical Society is continued, and Mr. J. E. Kingsbury has been added to the Committee as a representative of the Institution in place of Mr. W. R. Cooper, who, having been elected an Hon. Secretary of the Physical Society, is now an *ex-officio* member.

The Council notes with pleasure that the American Physical Society has identified itself with *Science Abstracts*, and that it is represented on the Committee by Professor E. H. Hall ; and, further, that the American Institute of Electrical Engineers is giving direct assistance in the work.

Having in view the increase in the quantity and scope of the matter to be abstracted, it appeared desirable to the Committee to divide the Abstracts into two Sections, one to be devoted to Physics and the other to Engineering, and with the sanction of the constituent Societies this was done at the commencement of the present year. At the same time it was seen that the arrangement under which the publication had hitherto been conducted could no longer be continued unchanged. A new basis of agreement was therefore adopted, under which the Institution and the Physical Society contribute certain fixed sums towards the General Expenses of publication, and a further payment for each copy supplied to its members. The gratuitous distribution of the Abstracts by the Institution was stopped as from

January 1st, and a small charge was levied upon each member requiring a copy. In this way the Council feels that the Institution is able to give the necessary assistance to a valuable publication without incurring very heavy charges for the supply of copies of the publication to those members who may not wish to receive it.

The sum of £920 shown in the accompanying Statement of Accounts as a contribution to *Science Abstracts* is the last annual payment under the old *régime;* the amount to be contributed in 1903 will be very much reduced.

Wiring Rules and Model General Conditions.

The Wiring Rules of the Institution have now been published, and have received the adhesion of the Council of the Incorporated Municipal Electrical Association. They have also been adopted by a number of supply undertakers and insurance offices.

A standing Committee has been appointed by the Council to consider all questions of revision, so that the rules may from time to time be amended and kept up to date.

The set of Model General Conditions drawn up by a special representative Committee has now also been published, and has been received favourably.

The Council earnestly hopes that the long and careful work expended in the preparation of the Wiring Rules and of the Model General Conditions will prove to be of great benefit to the Electrical industry.

Annual Premiums.

The Council has awarded the following premiums for papers and communications :—

The Institution Premium, value £25,

to Dr. J. A. Fleming, F.R.S., for his paper entitled "Photometry of Electric Lamps";

The Paris Electrical Exhibition Premium, value £10,

to Mr. M. B. Field, for his paper entitled "A Study of the Phenomenon of Resonance in Electric Circuits by the Aid of Oscillograms";

Two Extra Premiums, value £10 each,

one to Messrs. A. D. Constable and E. Fawssett jointly, for their paper entitled "Distribution Losses in Electric Supply Systems"; and the other to Dr. W. M. Thornton, for his paper entitled "Experiments on Synchronous Converters";

An Original Communication Premium, value £10,

to Messrs. A. Russell and C. C. Paterson, for their communication entitled "Sparking in Switches."

STUDENTS' PREMIUMS.

A premium, value £7, to J. GRIFFIN, for his paper on "Synchronous Electrical Machinery."

A premium, value £5, to F. J. HISS, for his paper on "An Analysis of some Points in Three-phase Motor Design."

A premium, value £5, to E. FISHER, for his paper on "Three-wire System of Electric Lighting by Continuous Current."

A premium, value £4, to A. G. ELLIS, for his paper on "The Paralleling of Alternators."

A premium, value £3, to T. H. VIGOR, for his paper on "The Photometry of Electric Lamps."

In accordance with precedent, the Council in making the awards of premiums has not taken into account the papers contributed by present members of the Council. Papers other than those of the Students' Section, which were not in type by the end of April, 1903, were reserved for consideration in awarding premiums in 1904; but certain papers which were received too late for consideration in 1902 have been taken into account this year.

SALOMONS SCHOLARSHIP.

The Council has awarded Salomons Scholarships, value £50 each, to Mr. G. B. DYKE, of University College, London; and to Mr. H. W. KEFFORD, of the Central Technical College.

DAVID HUGHES SCHOLARSHIP.

The award of the David Hughes Scholarship, value £50, has this year been made to Mr. W. H. WILSON, of King's College, London.

STUDENTS' CLASS.

Twelve meetings of the Students' Class have been held during the Session, at which papers have been read and discussed, and the work of the Section progresses steadily. Visits to the following places have been arranged during the Session:—

1902.

Nov. 27.—The Works of Messrs. Siemens' Bros. & Co., Limited, Woolwich, S.E.

Dec. 6.—The Works of the Central London Railway, Shepherd's Bush, W.

1903.

Jan. 17.—The Works of the India Rubber, Gutta Percha, and Telegraph Works Company, Silvertown, E.

" 31.—The Joint Works of the Notting Hill and Kensington Electricity Supply Companies, Ltd., Shepherd's Bush, W.

Feb. 7.—The Works of Messrs. Johnson & Phillips, Charlton, S.E.
„ 13.—The Works of the Electrical Power Storage Company, Limited, Millwall, E.
„ 20.—The Board of Trade Laboratory, Whitehall, S.W.
„ 27.— „ „ „
March 7.—The Works of the London United Tramways, Limited.
„ 12.—The Works of the Incandescent Electric Lamp Company, Limited, Hammersmith, W.
„ 28.—The Telephone Exchange of the General Post Office.
April 4.—The Islington Electricity Supply Works.
May 2.—The Works of the Western Electric Company.
„ 16.—The Works of Messrs. Elliott Bros., Lewisham.

During the Easter holidays a visit has been paid to the following Works in the neighbourhood of Manchester and Sheffield, in an excursion successfully organised by the Students' Committee, which has been fortunate in receiving the continued assistance of Mr. H. D. Symons as Hon. Secretary:—

Messrs. E. Allen & Co.
Messrs. Askham, Bros. & Wilson.
Messrs. John Brown & Co., Limited.
The British Westinghouse Electric Manufacturing Company, Ltd.
The Chloride Electrical Storage Company, Limited.
Messrs. Cooke & Co.
Messrs. S. Z. de Ferranti, Limited.
The Manchester Corporation Electricity Works.
The Nunnery Colliery Company.
The Sheffield Corporation Electricity Works.
The Sheffield Corporation Tramways Generating Station.
Messrs. Walker & Hall.

The Council records its thanks to the owners and managers of the several works, both in and around London, and in Sheffield and Manchester, for their assistance to the Students in thus throwing open their works to inspection.

Annual Dinner.

The Annual Dinner was held in the Grand Hall of the Hotel Cecil on the 17th of December, the company numbering about 326; an early adjournment was made to the adjacent Victoria Hall for conversation, and it is believed that the innovation was greatly appreciated.

Annual Conversazione.

The Annual Conversazione, held on the 1st of July at the Natural History Museum, gave the Institution the privilege of welcoming not only the members of the Incorporated Municipal Electrical Association, which was holding its Annual Convention in London at the time, but the Delegates to the International Tramways and Light Railways Congress, which was also in session in the capital during that week.

Annual Accounts and Financial Position.

The large increase in membership during the year, and the absence of unusual calls for expenditure, have allowed a substantial sum to be invested.

In the Annual Statement of Accounts, appended hereto, a slight change has been made in order to show clearly the financial result of the year's working, thus making it possible in future years to compare readily the results with those of former years. It will be seen that credit has been taken on the income side for that amount of arrears of subscriptions which, from the experience of former years, is estimated as being recoverable. On the other hand, sums received as entrance fees being considered rather as additions to capital than as income, have been carried direct to Capital Account. In conformity with modern usage the Income and Expenditure sides of the Statement of Accounts have been interchanged.

In the Balance Sheet for 1901, a sum of £90 9s. 6d. appears as representing the value of the Stock of Institution Journals, Ronalds Library Catalogues, etc., and a sum of £18 15s. 2d. as representing that of Cooke Manuscripts, on the 31st of December of that year. The value of old stock of Journals and publications being difficult to assess, it has been decided to discontinue the practice of including this stock as an Asset.

As the amount received in 1902 in respect of sales of the Institution Journal amounted, after deducting the cost of advertising, to £182 7s. 6d., the value (£108 14s. 8d.) of the stock of Journals and Cooke Manuscripts, as given in the last Balance Sheet, has been deducted from this sum, and the difference, £73 12s. 10d., appears on the creditor side of the Statement of Income and Expenditure for 1902, as the net proceeds of the sale of the Journal last year. The entries, "Stock of Institution Journals, Ronalds Library Catalogues, etc.," and "Stock of Cooke Manuscripts," cease therefore to appear in the Balance Sheet; and, in future, the proceeds from sales of Journals will appear as revenue.

Building Fund.

The Building Fund, which at the commencement of the year 1902 stood at £9,397 18s. 9d., was, on the 31st of December, £10,691 1s. 11d. The increase included a sum of £800 transferred from the surplus income, and a sum of £15 presented by the Engineering Society of the Finsbury Technical College.

The Council has to express its satisfaction at having also received during the later portion of the Session a donation of £76 19s. from 637 Students of the Institution. This amount was collected and forwarded spontaneously by the Committee of the Students' Section; for the work involved, the Council is grateful to the Committee, and especially to the Hon. Secretary of the Section, Mr. H. D. Symons. The Council particularly appreciates the spirit in which the gift was made to the Building Fund, and the evidence that it affords of the attachment of the younger members to the Institution.

The Institution Benevolent Fund.

At the request of the contributors to the Benevolent Fund, the management has now been transferred to a Committee consisting of the President and six members of the Council, with three contributors to the Fund who are not for the time being members of Council. This Committee is in the appointment of the Council.

The Wilde Benevolent Fund.

No grant has been made from this Fund during the year.

Local Honorary Secretaries.

During the past Session, Mr. R. H. Krause has retired from the office of Local Honorary Secretary and Treasurer for Austria-Hungary, owing to his change of residence, and Herr A. Von Boschan has been appointed in his place.

Mr. John Hesketh has succeeded Mr. R. O. Bourne as Local Honorary Secretary and Treasurer for Queensland, on the appointment of the latter as Commonwealth Public Service Inspector; and Mr. James Oldham is now Local Honorary Secretary and Treasurer for Uruguay in place of his brother, Mr. John Oldham.

Mr. W. Grigor Taylor, on leaving the East, has been obliged to give up his office of Local Honorary Secretary and Treasurer for the Straits Settlements.

To all of these retiring Officers the Council desires to convey its hearty thanks and its acknowledgment of the good services rendered by them to the Institution; and to those newly elected it expresses its gratification that they have undertaken to assist the Institution in their several districts.

At the suggestion of Mr. H. H. Kingsford, the Secretariat for Peru and Mexico has been divided, Mr. Kingsford retaining the office of Local Honorary Secretary and Treasurer for Peru. No appointment has yet been made to the Mexican Secretariat.

Visit of the Institution to Italy.

Immediately before Easter, 1903, a party of 117 members and others, and 27 ladies, visited the electrical works and railways of Northern Italy.

Arriving in Como on the 3rd of April, they visited the Valtellina Railway, and on the 6th of April continued their journey to Milan, whence they visited the Milan-Varese Electric Railway and the Power Stations at Paderno, Vizzola, and Tornavento, and the following works in and around Milan :—

The Porta Volta and S. Radagonda Stations of the Italian Edison Co.
Messrs. Gadda & Co. and Brioschi Finzi & Co.
Officine Meccaniche.
Messrs. Pirelli & Co.
Messrs. Riva, Monneret & Co.

The Milan Telephone Exchange of the Società Telefonica per l' alta Italia.
Messrs. Franco Tosi.
Messrs. Gavazzi & Co.
Messrs. Frua and Banfi.

While at Como, an opportunity was taken to arrange for a corporate visit to the tomb of Alessandro Volta; a wreath was laid upon the tomb by the President in the name of the Institution, and a bronze shield with a suitable inscription, subscribed for by the Students' Section, was presented by Mr. J. R. Hewett, acting on their behalf.

The Council desires to express its deep indebtedness to Professor Ascoli and the Associazione Elettrotecnica Italiana, and specially to Signor A. Bertini, the President, and Signor G. Semenza, the Secretary of the Milan Section of the Association, to the Mayors and Councils of Como and Camnago Volta, and to the Adriatic and Mediterranean Railway Companies, the Italian Edison Company, the Società Lombarda per Distribuzione di Energia Elettrica, the Compagnie Thomson Houston de la Méditerranée, to the firms mentioned above, and to the many other firms and individuals who in various ways contributed to the very hearty welcome, which was greatly appreciated by the visitors.

The warmth of the reception and the generous hospitality of the Italian hosts will live in the memory of all who were fortunate enough to be of the party.

Departing from previous practice, the Institution, without accepting corporate responsibility, undertook the management of the arrangements for railway and hotel accommodation for those of the number who were not inclined to make their own dispositions. All the expenses connected with the excursions were borne by those availing themselves of the accommodation provided. This plan proved very successful, owing to the tireless energy of Mr. McMillan, the Secretary, and to the devotion of the staff.

Visit to America in 1904.

The Council has received and accepted an invitation from the American Institute of Electrical Engineers to visit the United States in 1904. The McGill University, of Montreal, has invited the two Institutions to hold a joint meeting in their building at this time. The invitations, both from the American Institute and from the McGill University, are couched in the most cordial terms, and the Council hopes that it may be possible to arrange not only for a visit to the Eastern States of America and to the St. Louis Exhibition, but also for the proposed joint meeting in Canada.

The Factories and Workshops Acts, 1901.

The Institution has been in close touch with the Home Office in regard to the provisions of the Factory Act with reference to the employment of "young persons" under the age of eighteen in electricity works; and the Home Secretary has now made such provisions

as are in his power to allow of the employment of such young persons under suitable conditions. The Council is indebted to the Home Secretary for having received the representations voiced by the Institution in deference to the request of the Conference referred to in the last Report.

It is understood that no special regulations for electricity works under the Factories and Workshops Act will be made without an opportunity being first given to the industry to consider them, and, if necessary, to make representations to the Home Office with reference to them.

PARLIAMENTARY AND INDUSTRIAL COMMITTEE.

A Parliamentary and Industrial Committee has been appointed by the Council. "To collect information, consider, and report to the Council on proposed legislation, regulations, enactments, and policy, so far as they may be expected to affect Electrical Industries generally from the Engineering point of view; and to make recommendations to the Council as to the advisability of taking action thereon, or otherwise."

CODE OF PROFESSIONAL ETIQUETTE.

A Committee was appointed by the Council to inquire whether any steps should be taken with regard to the question of professional etiquette. This Committee drew up a code of etiquette which, after consideration, was adopted and published by the Council during the year 1902, with the object of making generally known the views of the Council on this difficult subject.

NATIONAL PHYSICAL LABORATORY.

Professor Ayrton's period of office as a representative of the Institution on the General Board of the National Physical Laboratory having expired, and he being ineligible for re-appointment, Mr. Robert Kaye Gray has been nominated by the Council to serve in his stead.

ENGINEERING STANDARDS COMMITTEE.

The work of this Committee, in which this Institution is associated with the Institution of Civil Engineers, the Institution of Mechanical Engineers, the Institution of Naval Architects, and the Iron and Steel Institute, is progressing steadily. This Institution has contributed £250, and the Council learns with pleasure that a grant of £3,000 has been made by Government, towards the expenses of the present year.

WORK OF THE INSTITUTION.

The work of the Institution continues steadily to increase, both in amount and importance. During the past year there have been 21 Committees at work. 16 General Meetings, 4 Special General Meetings of Members, 26 Council Meetings, and 93 Committee Meetings have been held.

New Offices.

The Members of Council have long had before them the fact that the accommodation afforded by the offices in which the Institution has had its home for the last thirteen years had become inadequate. Feeling that the time had arrived when a change should be made, it was decided to move to 92, Victoria Street, Westminster, where the conditions of light and space are more in accordance with the needs of the Institution. The increased accommodation will permit of the Library being rearranged and considerably enlarged. The removal was effected in March without any serious dislocation of business.

The Coronation of Their Majesties King Edward VII. and Queen Alexandra.

It will be remembered that on the occasion of the Annual Conversazione last year, when His Majesty the King was lying dangerously ill, a special resolution was passed at that gathering, and that this resolution received a gracious acknowledgement from Her Majesty the Queen. Fortunately a few weeks later the Institution was able to submit a loyal and dutiful Address in connection with the Coronation.

The Library.

Report of the Secretary.

I have to report that the accessions to the Library during the twelve months, from May 15th, 1902, to the date of the Annual General Meeting, numbered 90; nearly all of these were kindly presented by the authors or publishers.

The supply of specifications of electrical patents and that of abridgments of specifications relating to electricity and magnetism are continued by the kindness of H.M. Commissioners of Patents, and the arrangement is still in force whereby the specifications of all electrical patents published during any week are placed on the Library table on the following Monday morning.

The periodicals or printed proceedings of other societies received regularly are, with some additions, the same as last year, as may be seen by the list appended hereto.

The number of visitors to the Library in the twelve months from May 23rd, 1902, to the date of the Annual General Meeting, has been 366, of whom 17 were non-members.

By order of the Council the Library was closed for a fortnight during March, at the time of the removal into the new rooms of the Institution.

WALTER G. McMILLAN, *Secretary*.

APPENDIX TO SECRETARY'S REPORT.

TRANSACTIONS, PROCEEDINGS, &c., RECEIVED BY THE INSTITUTION.

BRITISH.

Asiatic Society of Bengal, Journal and Proceedings.
Cambridge Philosophical Society.
Engineering Association of New South Wales.
Greenwich Magnetical and Meteorological Observations.
Institute of Patent Agents, Transactions.
Institution of Civil Engineers, Proceedings.
Institution of Mechanical Engineers, Proceedings.
Iron and Steel Institute, Proceedings.
King's College Calendar.
Liverpool Engineering Society, Proceedings.
Municipal Electrical Association, Proceedings.
National Physical Laboratory Report.
North of England Institute of Mining and Mechanical Engineers Transactions.
Physical Society, Proceedings.
Royal Dublin Society, Transactions and Proceedings.
Royal Engineers' Institute, Proceedings.
Royal Institution, Proceedings.
Royal Meteorological Society, Proceedings.
Royal Scottish Society of Arts, Transactions.
Royal Society, Proceedings.
Royal United Service Institution, Proceedings.
Society of Arts, Journal.
Society of Chemical Industry, Journal.
Society of Engineers, Proceedings.
Surveyors Institution, Transactions.
University College Calendar.

AMERICAN AND CANADIAN.

American Academy of Science and Arts, Proceedings
American Institute of Electrical Engineers, Transactions.
American Philosophical Society, Proceedings.
American Society of Mechanical Engineers, Transactions.
Canadian Society of Civil Engineers, Transactions.
Cornell University, Library Bulletin.
Engineers' Club of Philadelphia, Proceedings.
Franklin Institute, Journal.
John Hopkins University, Circulars.
Nova Scotia Institute of Science, Proceedings.
Ordnance Department of the United States, Notes.
Western Society of Engineers, Journal.

BELGIAN.

Association des Ingénieurs Électriciens sortis de l'Institut Electro-Technique Montefiore, Bulletin.
Société Belge d'Électriciens, Bulletin.

DANISH.

Tekniske Forening, Tidsskrift.

DUTCH.

Koninklijk Institut van Ingenieurs, Tijdschrift.

FRENCH.

Académie des Sciences, Comptes Rendus Hebdomadaires des Séances.
Association Amicale des Ingénieurs-Électriciens, Bulletin Mensuel.
Société Française de Physique, Bulletin des Séances.
Société des Ingénieurs Civils, Mémoires.
Société Internationale des Électriciens, Bulletin.
Société Scientifique Industrielle de Marseille, Bulletin.

GERMAN.

Verein Deutscher Ingenieure, Zeitschrift.
Verein zur Beförderung des Gewerbfleisses, Verhandlungen.

ITALIAN.

Associazione Elettrotecnica Italiana, Atti.

RUSSIA.

Section Moscovite de la Société Impériale Technique Russe.

LIST OF PERIODICALS RECEIVED BY THE INSTITUTION.

BRITISH.

Cassier's Magazine.
Electrical Engineer.
Electrical Review.
Electrical Times.
Electrician.
Electricity.
Electro-Chemist and Metallurgist.
Engineer.
Engineering.
Engineering Times.
English Mechanic and World of Science.
Feilden's Magazine.
Illustrated Official Journal, Patents.
Indian and Eastern Engineer.
Invention.

Light Railway and Tramway Journal.
Mechanical Engineer.
Nature.
Page's Magazine.
Philosophical Magazine.
Scottish Electrician.

AMERICAN.

American Electrician.
Electrical Review.
Electrical World and Electrical Engineer.
Electricity.
Engineering News.
Journal of the Telegraph.
Physical Review.
Scientific American.
Street Railway Journal.
Technology Quarterly.
Western Electrician.

AUSTRIAN.

Zeitschrift für Elektrotechnik.

DUTCH.

De Ingenieur.

FRENCH.

Annales Télégraphiques.
L'Éclairage Électrique.
L'Électricien.
L'Industrie Électrique.
Journal de Physique.
Journal Télégraphique.
Le Mois Scientifique et Industriel.

GERMAN.

Annalen der Physik und Chemie.
Beiblätter zu den Annalen der Physik und Chemie.
Centralblatt für Accumulatoren und Elementenkunde.
Electrotechnischer Anzeiger.
Electrotechnische Zeitschrift.
Zeitschrift für Elektrochemie.
Zeitschrift für Instrumentenkunde.

ITALIAN.

L'Elettricità.
Giornale del Genio Civile.
Il Nuovo Cemento.

SPANISH.

La Ingenieria.

The Institution of

STATEMENT OF INCOME AND ENDING 31st

Dr.

EXPENDITURE.

	£ s. d.	£ s. d.
To MANAGEMENT :—		
Salaries	1,276 15 0	
Retiring Allowance	300 0 0	
Accountants' Fees	15 15 0	
Addressing of Circulars and Notices... ...	51 11 0	
Printing and Stationery	393 15 5	
Postage	649 13 3	
Telephone	17 0 0	
		2,704 9 8
„ PUBLICATIONS :—		
Journal (Printing and Illustrating)	1,063 13 1	
"Science Abstracts" (Contribution)	920 0 0	
Wiring Rules	7 4 2	
Model General Conditions for Contracts ...	51 1 0	
		2,041 18 3
„ MEETINGS :—		
Advance Proofs, Refreshments, &c.	143 12 0	
Reporting	58 16 0	
		202 8 0
„ RENT, LIGHTING, AND FIRING		337 16 8
„ INSURANCE		9 15 0
„ DEPRECIATION :—		
Library (5 %)	68 8 11	
Furniture (5 %)	13 0 7	
		81 9 6
PREMIUMS		107 11 3
„ CONVERSAZIONE (irrespective of Printing and Postage) ...		309 15 10
„ ANNUAL DINNER		21 1 4
„ LOCAL SECTIONS		321 13 1
„ COMMITTEE ON ELECTRICAL LEGISLATION		48 10 6
„ GENERAL EXPENSES :—		
Congratulatory Addresses to H.M. the King and to the Owens College, Manchester ...	18 13 10	
Coronation Decorations	10 0 0	
Memorial Wreath	5 5 0	
Sundries	92 1 0	
		125 19 10
„ BALANCE carried to General Fund, being excess of Income over Expenditure		950 19 9
		£7,263 8 8

EXPENDITURE FOR THE YEAR DECEMBER, 1902.

Cr.

INCOME.

	£	s.	d.	£	s.	d.
By Subscriptions for 1902 :—						
Received	6,173	17	6			
Outstanding (Estimated Value)	300	0	0			
				6,533	17	6
„ Publishing Fund				1	1	0
„ Dividends on Investments :—						
Life Compositions	£165	17	4			
General Fund	157	8	1			
				323	5	5
„ Interest on Cash on Deposit				30	15	3
„ Journal :—						
Sales (Net Proceeds)	73	12	10			
Advertisements	300	16	8			
				374	9	6
				£7,263	8	8

LIFE

Dr.

	£	s.	d.
To Amount (as per last Account)	5,215	0	0
" Life Compositions received during 1902	166	10	0
	£5,381	10	0

COMPOSITIONS.

Cr.

							£	s.	d.
By Investments (as per last Account) :—									
£400	0	0	New South Wales 4 % Bonds ...	£414	15	0			
318	0	0	Cape of Good Hope 4 % Consolidated Stock	306	0	0			
1,679	19	5	India 3½ % Stock	1,776	5	0			
120	0	0	South-Eastern Railway 5 % Debenture Stock	204	16	6			
355	5	10	Canada 3 % Stock	352	13	6			
289	17	4	Midland Railway 2½ % Consolidated Perpetual Preference Stock	274	11	10			
6	0	0	East Indian Railway Class "C" Annuity	185	1	9			
87	0	0	Great Eastern Railway 4 % Consolidated Preference Stock ...	130	15	2			
175	0	0	Great Eastern Railway 4 % Debenture Stock	251	5	5			
4	13	6	Great Indian Peninsula Railway "B" Annuity	120	1	6			
143	0	0	Southwark and Vauxhall Water Co. 4 % A. Debenture Stock...	207	17	9			
520	0	0	Staines Reservoirs 3 % Guaranteed Debenture Stock	539	2	3			
200	0	0	Glasgow and South-Western Railway 4 % Preference Stock (1894)	276	5	0			
29	0	0	Madras Railway 5 % Stock ...	44	9	4			
57	0	0	South Indian Railway 4½ % Debenture Stock	84	0	0			
30	0	0	Burma Railway Co.'s Stock ...	30	12	3			
							5,198	12	3
" Investment Purchased in 1902 :—									
40	0	0	East Indian Railway 4½ % Debenture Stock				57	3	7
							£5,255	15	10
" Balance uninvested carried to Balance Sheet							125	14	2
							£5,381	10	0

BUILDING

Dr.

		£	s.	d.
To Amount (as per last Account) :—				
Invested	£9,202 4 11			
Uninvested	195 13 10			
		9,397	18	9
„ Dividends received during 1902		277	2	9
„ Subscriptions received during 1902		207	14	0
„ Surplus from Vellum Diplomas		8	6	5
„ Amount transferred from General Fund in 1902		800	0	0
		£10,691	1	11

FUND.

Cr.

			£ s. d.
By Investments (as per last Account) :—			
£450 0 0	Canada 4 % Reduced Stock ...	£504 0 0	
524 13 0	Canada 3 % Stock	553 10 1	
181 0 0	Great Western Railway 4½ % Debenture Stock	324 17 8	
418 0 0	South-Eastern Railway 3½ % Preference Stock	555 18 9	
370 0 0	London and South-Western Railway Preferred Ordinary Stock ...	510 12 0	
520 0 0	London and South-Western Railway 4 % Consolidated Preference Stock	821 12 0	
190 16 8	India 3½ % Stock	229 9 6	
387 0 0	Great Eastern Railway 4 % Consolidated Preference Stock	575 17 8	
529 12 0	Midland Railway 2½ % Consolidated Perpetual Preference Stock ...	500 0 0	
23 7 5	Great Indian Peninsula Railway "B" Annuity	600 2 6	
80 0	London and South-Western Railway 3½ % Preference Stock	99 18 3	
504 0 0	Staines Reservoirs 3 % Guaranteed Debenture Stock	528 5 0	
670 0 0	Glasgow and South-Western Railway 4 % Preference Stock (1894) ...	925 11 9	
75 0 0	Great Eastern Railway 4 % Debenture Stock	107 13 7	
15 0 0	South-Eastern Railway 3 % Preference Stock	15 0 0	
220 0 0	Madras Railway 5 % Stock	340 0 5	
343 0 0	South Indian Railway 4½ % Debenture Stock	509 2 0	
320 0 0	South-Eastern Railway Preferred Ordinary Stock	511 1 0	
970 0 0	Burma Railway Co.'s Stock... ...	989 12 9	
			£9,202 4 11
„ Investment purchased in 1902 :—			
670 0 0	East Indian Railway 4½ % Debenture Stock		945 2 10
			£10,147 7 9
„ Balance uninvested carried to Balance Sheet			543 14 2
			£10,691 1 11

SALOMONS SCHOLARSHIP

Dr.

	£	s.	d.
To Amount (as per last Account)	2,126	19	3
	£2,126	19	3

SALOMONS SCHOLARSHIP

Dr.

	£	s.	d.
To Amount paid to Scholars in 1902...	62	10	0
„ Balance carried to Balance Sheet	80	1	2
	£142	11	2

DAVID HUGHES SCHOLAR-

Dr.

	£	s.	d.
To Amount (as per last Account)	2,000	0	0
	£2,000	0	0

DAVID HUGHES SCHOLAR-

Dr.

	£	s.	d.
To Amount paid to Scholars in 1902...	50	0	0
„ Balance carried to Balance Sheet	45	13	6
	£95	13	6

WILDE BENEVOLENT

Dr.

	£	s.	d.
To Amount (as per last Account)	1,500	0	0
	£1,500	0	0

WILDE BENEVOLENT

Dr.

	£	s.	d.
To Amount invested in P.O. Savings Bank...	108	18	1
„ Balance uninvested carried to Balance Sheet	2	9	6
	£111	7	7

FUND CAPITAL.

				Cr.		
				£	s.	d.
By Investments :—						
£1,500 New South Wales 3½ % Stock ...	£1,556	5	9			
500 Cape of Good Hope 3½ % Stock ...	570	13	6			
				2,126	19	3
				£2,126	19	3

FUND INCOME.

	Cr.		
	£	s.	d.
By Balance (as per last Account)	72	16	6
„ Dividends received in 1902	69	14	8
	£142	11	2

SHIP FUND CAPITAL.

	Cr.		
	£	s.	d.
By Investment :—£2,045 Staines Reservoirs 3 % Guaranteed Debenture Stock	1,998	15	0
„ Balance uninvested carried to Balance Sheet	1	5	0
	£2,000	0	0

SHIP FUND INCOME.

	Cr.		
	£	s.	d.
By Balance (as per last Account)	34	10	3
„ Dividends received in 1902	61	3	3
	£95	13	6

FUND CAPITAL.

	Cr.		
	£	s.	d.
By Investment :—£875 Great Eastern Railway Metropolitan 5 % Guaranteed Stock	1,493	16	3
„ Amount invested in P.O. Savings Bank	6	3	9
	£1,500	0	0

FUND INCOME.

	Cr.		
	£	s.	d.
By Amount (as per last Account)	64	10	10
„ Dividends received in 1902	43	12	6
„ Interest	3	4	3
	£111	7	7

BALANCE SHEET,

Dr.

LIABILITIES.

				£	s.	d.
To Sundry Creditors				791	8	4
„ Local Sections :—						
Due to Hon. Sec. Dublin Section	£1	15	2			
do. do. Manchester Section	34	11	2			
do. do. Newcastle Section	6	11	9			
				42	18	1
„ Subscriptions received in advance :—						
On Account of 1903	154	18	0			
do. do. 1904, 1905, and 1906	5	4	0			
				160	2	0
„ Salomons Scholarship Fund Income				80	1	2
„ David Hughes Scholarship Fund :—						
Capital uninvested	1	5	0			
Income	45	13	6			
				46	18	6
„ Wilde Benevolent Fund Income				2	9	6
„ Entrance Fees				849	6	0
„ Life Compositions uninvested				125	14	2
„ Building Fund uninvested				543	14	2
„ General Fund :—						
As per last Balance Sheet	5,751	12	7			
Add Excess of Income over Expenditure	950	19	9			
Subscriptions for years previous to 1902 received in 1902	374	10	0			
Subscriptions for years previous to 1902 outstanding on December 31st, 1902 (Estimated Value)	50	0	0			
	7,127	2	4			
Less Transferred to Building Fund	800	0	0			
				6,327	2	4
				£8,960	14	3

W. G. McMILLAN,
Secretary.

We beg to report that we have examined the above Balance Sheet and the Bankers' Certificates as to the Securities, and in our opinion the State- exhibit a true and correct view of the state of the affairs of the Institution at cost price. We hereby certify that all our requirements as Auditors have

ALLEN, BIGGS & CO.,
Chartered Accountants,
38, PARLIAMENT STREET, S.W.

24th April, 1903.

31st DECEMBER, 1902.

Cr.

ASSETS.

		£ s. d.
By Cash :—		
At Bankers	1,570 9 0	
Petty Cash	27 18 4	
		1,598 7 4
„ Local Sections :—		
In hands of Hon Sec. Birmingham Section...	6 0 7	
do. do. do. Glasgow Section ...	11 9 9	
		17 10 4
„ Investments, General Fund :—		
£1,418 8 0 Midland Railway 2½% Consolidated Perpetual Preference Stock	£1,200 0 0	
918 3 2 India 3½ % Stock	973 17 10	
52 13 8 Great Indian Peninsula Railway "B" Annuity	1,239 17 9	
721 0 0 Madras Railway 5% Stock	1,114 14 0	
410 0 0 East Indian Railway 4½ % Debenture Stock...	586 1 7	
		5,114 11 2
„ Subscriptions in Arrear (Estimated Value)		410 0 0
„ Sundry Debtors		275 3 3
„ National Telephone Co. Deposit...		0 10 0
„ Furniture :—		
As per last Balance Sheet	251 11 2	
Additions during 1902	9 0 0	
	260 11 2	
Less Depreciation (5 %)	13 0 7	
		247 10 7
„ Books, Pictures, &c., other than the Ronalds Library :—		
As per last Balance Sheet	1,351 9 9	
Additions during 1902	17 8 9	
	1,368 18 6	
Less Depreciation (5 %)	68 8 11	
	1,300 9 7	
„ Stock of Vellum Diploma Forms	5 12 0	
		1,306 1 7
		£8,969 14 3

Statements of Account with the Books and Vouchers of the Institution, and ments are correct, and the Balance Sheet is properly drawn up so as to as shown by its books. The Securities have been included in the Accounts been complied with.

F. C. DANVERS
SIDNEY SHARP } *Honorary Auditors.*

The PRESIDENT: I have now to move that the Report of the Council as presented be received and adopted, and that it be printed in the Journal of the Proceedings of the Institution.

General WEBBER: I have great pleasure in seconding the proposal, more especially as the departure is a new one. Generally we have occupied the time of this meeting by reading this document, which is very interesting but, according to some of our friends, rather dry, at least, when it is read out. At the same time, knowing the immense amount of work that it represents on the part of our able Secretary, I think every one who reads it alone and at home will be interested and will recognise what he has done in the past year. I beg to second the proposal that has just been made to you by the President, that the Report be taken as read.

No further remarks being offered, the resolution was put to the meeting and carried unanimously.

The PRESIDENT: You have also had in your hands the Statement of Accounts, which were referred to in the Report, and which have been carefully examined and are certified as correct by the Honorary Auditors, Messrs. Danvers and Sharp. As you have had them before you, I do not want to occupy your time unnecessarily. I will formally move that the Statement of Accounts and Balance Sheet, of which copies were sent to the members with the notice convening the Annual General Meeting, be taken as read.

The motion was carried.

The PRESIDENT: I have now to propose, "That the Statement of Accounts and Balance Sheet for the year ending December 31, 1902, as presented be received and adopted."

Mr. ROBERT HAMMOND: I beg to second that, and would like to say that the accounts for the past year show a very healthy improvement upon those of the year before, due to the expansion of the Institution from year to year. The subscriptions show an increase for 1902 over 1901 of £880 10s. 6d.; the entrance fees show an increase for 1902 over 1901 of £232 13s.; our receipts from other sources of £224 13s. 4d.; and the expenditure shows an excess of only £374 3s. 5d.; the summary of the accounts therefore showing a net improvement of 1902 over 1901 of £963 13s. 5d.

The resolution was then put to the meeting and carried unanimously.

Mr. ROBERT HAMMOND: It gives me much pleasure to propose a vote of thanks to the Institution of Civil Engineers, who have in the past year, as they have kindly done in years gone by, placed their hall at our disposal. Of course the time may come when we shall have our own hall, but in the meantime we cannot express our gratitude too strongly to the Institution of Civil Engineers for their great kindness. The motion is, "That the best thanks of the Institution be tendered to the President, Council, and Members of the Institution of Civil Engineers for the great privilege of holding our evening meetings in the rooms of that Institution."

Mr. J. H. RIDER: I have much pleasure in seconding the vote of thanks to the Institution of Civil Engineers.

The resolution was put to the meeting and carried unanimously.

Mr. H. E. HARRISON: I have to propose, "That the members of the Institution of Electrical Engineers hereby express their cordial thanks to the Society of Arts for the great privilege of holding their evening meetings in May in the rooms of that Society." I need hardly say that it is a very great privilege to us when the Institution of Civil Engineers is unable to give us the use of its theatre that we should have friends like the Society of Arts on whom we may fall back to get us out of our difficulties. I have therefore very great pleasure in proposing this vote of thanks.

Mr. L. GASTER: I have much pleasure in seconding this vote. I have the pleasure of being a member of the Society of Arts myself, but I hope that it is not out of place for me to second the resolution.

The resolution was put to the meeting and carried with acclamation.

Mr. W. H. PATCHELL: The next resolution has been put into my hands—"That the thanks of the Institution be given to the Local Honorary Secretaries and Treasurers for their services during the past year." I think as time goes on we get more and more of the life of the Institution, not only in the Provinces but abroad, and the work done by the Honorary Local Secretaries and Treasurers is more and more in evidence, and we owe them an increasing debt of gratitude.

Mr. R. J. WALLIS-JONES: I have much pleasure in seconding the resolution that the thanks of the Institution be given to the Local Honorary Secretaries and Treasurers for their services during the past year.

The resolution was put to the meeting and carried unanimously.

Mr. E. O. WALKER: I have much pleasure in proposing "That the thanks of the Institution be accorded to Professor W. E. Ayrton and Mr. Robert Hammond, for their kind services rendered successively in the office of Honorary Treasurer during the past twelve months." I am sure that we all regret the occasion of Professor Ayrton, after so long a time fulfilling his duties with such great tact and kindness, having to resign his office on account of ill-health, and we owe him special thanks for all the work he has undertaken in connection with it. On behalf of the members I beg to thank Mr. Hammond for having so kindly consented to undertake the onerous duties of Treasurer, and to say that we shall value his services.

Mr. FLEETWOOD: I have great pleasure in seconding the motion.

The PRESIDENT: You have heard the motion put before you. I have no doubt it will be passed with acclamation as usual.

The resolution was carried by acclamation.

Mr. J. SWINBURNE: I have much pleasure in proposing a vote of thanks to the Honorary Auditors, Mr. Danvers and Mr. Sharp, and to the Honorary Solicitors, Messrs. Wilson, Bristows and Carpmael. We are all most grateful to business people who give up their valuable time to render services of that sort to the Institution.

Mr. W. DUDDELL: I have much pleasure in seconding the resolution.

The resolution was carried unanimously.

The PRESIDENT: I have now to announce that the candidates balloted for on the two lists are certified as duly elected.

Members.

Geo. Olver Donovan.
Joseph Richmond.
Charles Tothill.

Associate Members.

Robert M. Abraham.
William Adams.
Wm. Thomson Anderson.
Charles Jas. Beaver.
Arthur Bloemendal.
Joseph Norman Bulkeley.
Godfrey R. Chaplin.
Alan Ernest Leofric Chorlton.
Frederic Charles Geary.
Reuben Henry Harvey.
Percival Thomas Moor.
Henry Eoghan O'Brien.
Frank Augustus Parker.
Henry Mark Pease.
Geo. Gwendower L. Preece.
William Lincoln Smith.
John Robert Williams.

Associates.

Harry Bowthorpe.
Matthew Cable.
Chas. Wm. Clack.
Eustace Reginald Conder.
Wm. Griffith Counsell.
Dover Augustus G. de Horsey Farrant.
Arthur Frederic Fitzhardinge.
Horace William Woodness Henderson.
William A. Kennett.
William Hamilton Wilson.

Students.

Lennox Edelsten Agnew.
Frederick William Allen.
William Francis Bartram.
James Williamson Campbell.
Crellin Cartwright.
Chas. Bernard Catt.
Richard Chancellor.
Michael Dermot Cloran.
Harold Emmott.
Hugh Whitmore Franks.
Wm. Francis Furse.
Reginald Glanfield.
Albert Reginald Goonetilleke.
Evelyn Alfred Gurney-Smith.
Robert Harvey-George.
Herbert F. Hodges.
Walter Edward King.
Arthur Justin Patrick McCarthy.
Marcus Macdonald.
Patrick J. McElligott.
Richard Ward Passmore.
Francis E. Pingriff.
Sidney Reynill Smith.
Geo. Wilfred Stubbings.
Harold Dalbiac Taylor.
Clive Bennett Tutt.
Edward Bradford Ware.
Herbert R. Whiteley.

I have also to announce that no nominees having been received other than those announced at the Ordinary General Meeting on April 23rd, the Council nominees are, in accordance with No. 45 of the Articles of Association, duly elected to their respective offices, and the following constitute the Council and Honorary Officers for the twelve months 1903–1904 :—

President.

ROBERT KAYE GRAY.

The Past Presidents.

The Chairmen of Local Sections.

Vice-Presidents.

Dr. J. A. FLEMING, F.R.S.
JOHN GAVEY.
J. E. KINGSBURY.
Sir O. LODGE, F.R.S.

Members of Council.

Sir J. WOLFE BARRY, K.C.B., F.R.S.
T. O. CALLENDER.
S. DOBSON.
B. DRAKE.
S. Z. DE FERRANTI.
FRANK GILL.
F. E. GRIPPER.
H. E. HARRISON, B.Sc.
Lt.-Col. H. C. L. HOLDEN, R.A., F.R.S.
G. MARCONI.
W. M. MORDEY.
The Hon. C. A. PARSONS, F.R.S.
W. H. PATCHELL.
J. H. RIDER.
A. A. CAMPBELL SWINTON.

Associate Members of Council.

W. DUDDELL.
SYDNEY MORSE.
A. J. WALTER.

Honorary Auditors.

FREDERICK C. DANVERS.
SIDNEY SHARP.

Honorary Treasurer.

R. HAMMOND.

Honorary Solicitors.

Messrs. WILSON, BRISTOWS, & CARPMAEL.

Mr. HAMMOND: I have pleasure in moving a very hearty vote of thanks to our President for presiding at this meeting to-day.

Mr. W. MCGREGOR: I do not think that it requires any seconding, but coming as I have from a long distance, I should like to join in expressing what pleasure we have in attending this meeting, and I second the vote of thanks to our President.

The PRESIDENT: I am very much indebted to you, gentlemen, for your kindness.

OBITUARY NOTICES.

Sir FREDERICK AUGUSTUS ABEL, who passed away at his residence in Whitehall Court on the 6th of September, 1902, was born on the 17th of July, 1827, in Poland Street, Oxford Street.

At the age of seventeen he commenced his studies under Dr. Ryan at the Royal Polytechnic Institution, and a year later entered the then newly-formed Royal College of Chemistry, where he worked under Hofmann, first as pupil and then as assistant. In 1847–8–9 he read his first three papers before the Chemical Society. In 1851 he became lecturer in Chemistry under Stenhouse at St. Bartholomew's Hospital, and in 1853 succeeded to the Chair of Chemistry, previously occupied by Faraday, in the Royal Military Academy at Woolwich. Whilst here, he was appointed to be, first the scientific adviser, and then, in about the year 1854, chemist to the War Office.

From 1854 to 1888 he held the last-named position, and was thus intimately associated with the modern development of explosives and the applications of steel to naval and military purposes. His name will always be specially remembered in connection with gun-cotton and cordite, with the masterly researches on explosives in which he collaborated with Sir Andrew Noble, and with his recommendations on the mode of testing the flash-point of petroleum. In course of his work at the War Office, Sir Frederick necessarily gave much attention to the application of electricity to submarine mining and for military purposes generally. In 1874 he read before the Institution, then the Society of Telegraph Engineers, a paper embodying some of his experiences, and entitled "Notes relating to Electric Fuses." In 1887 Sir Frederick became the Organising Secretary of the Imperial Institute.

A brilliant and indefatigable worker in many fields of labour, the estimation in which he was held by his fellows is shown by the long list of distinguished positions that he held. Sir Frederick Abel was President of the Chemical Society from 1875 to 1877, of the Institute of Chemistry in 1881 and 1882, of the Society of Chemical Industry in 1883, of the Chemical Section of the British Association in 1887, of the Iron and Steel Institute in 1891, and of the British Association at Leeds in 1890. He had also acted as Chairman of the Council of the Society of Arts, and as Chairman of the Executive Committee of the City and Guilds of London Institute. He received the Companionship of the Order of the Bath in 1877, and, after having been knighted in 1883, became K.C.B. in 1891; he was made baronet in 1893, and in 1901 received the Grand Cross of the Royal Victorian Order. In addition to the above honours, he received honorary degrees at Oxford and Cambridge, and was at different times the recipient of the Albert, Royal, Telford, and Bessemer Medals.

Sir Frederick Abel was elected a Member of this Institution, then the Society of Telegraph Engineers, on the 16th of November, 1871; he was a Member of Council in 1873 and 1874, Vice-President in 1875 and 1876, and President in 1877. From 1887 to the time of his death

he was one of the Trustees of the Institution, and although, during his later years, the pressure of other engagements, together with impaired health, prevented his attending the Meetings of the Institution, he continued to the end to take a keen interest in its work.

J. S.

FREDERICK BATHURST, born in 1866, was the eldest son of Colonel Bathurst of the Coldstream Guards, and grandson of General Sir James Bathurst.

His electrical career commenced at Finsbury Technical College, where he went through a course under Professor Ayrton, after which he was articled to the late firm of Woodhouse & Rawson, Limited. In 1889 he went to the United States, and after visiting many places of interest, obtained an important position at the works of the Edison General Electric Co., where he was associated with Mr. Edison in his laboratory experiments. He remained with Mr. Edison until 1894, when he was summoned home to the death-bed of his father; after this Mr. Bathurst took a long holiday in France, Germany, Holland and Switzerland, with the object of acquiring information regarding electrical progress in those countries. He then returned to the United States, where he took leave of the many friends he had made during his previous stay there, and, on returning to England, took over the Conduit Department of the General Electric Co., Ltd., and introduced the Insulated Conduit System in this country. He devoted great personal energy to the work, and was rewarded with a large measure of success.

He remained with the General Electric Co. for about four years, when the owners of the patents decided to form a separate company in order to advance the interests of Insulated Steel Conduit still more, and Mr. Bathurst joined the Conduit & Insulation Co. for this purpose. After two or three years, however, he found that his energies were somewhat fettered in a Limited Company, and he decided to become a free agent in order to develop the system alone. He, therefore, severed his connection with this Company, and, at the moment of his untimely death, was arranging to put on the market further improvements and new lines of Steel Conduit.

In 1897 he married Florence, second daughter of Mr. Thomas Sellars of Nottingham, by whom he had two sons, one of whom unfortunately pre-deceased him. At the time of his marriage the remembrance which gave him the greatest pleasure was a signed photograph from Mr. Edison, "Wishing Bathurst all good luck and happiness on his wedding day."

Mr. Bathurst was an indefatigable worker, and all that he did was carried out with that push and energy which was characteristic of the man, and which unfortunately appears to have overstrained his constitution. Besides his actual ability for business he was also an able speaker and writer, as was instanced by the papers which he read before various societies, of which may be specially mentioned that entitled "The Electric Wiring Question," read before the Institution on the 28th of November, 1895, and published in the Institution Journal vol. 24,

p. 582. One of the papers which earned for him special distinction was that on "Prevention of Fire Risk," for which he was awarded by the Society of Arts a premium of £25 and their Gold Medal.

For many years he had been subject to asthma, and on the 27th of September, 1902, after a severe attack, he retired to rest and passed away in his sleep.

He was a man for whom all who came in contact had great respect, not only by reason of his business qualifications and the enthusiasm that he had for his particular hobby, but also for his sterling personal qualities, and his death occasioned the greatest regret amongst all members of the electrical profession.

Mr. Bathurst was elected a Student of the Institution on the 14th of February, 1884, and was transferred to the class of Associates on the 14th of February, 1889, and to the class of Associate Members on the 9th of February, 1899. V. Z.

FRANK BOLTON, who had occupied the post of Superintendent of the Eastern Telegraph Company at Trieste, Austria, since 1882, and had acted as that Company's agent with the Austrian Government since 1891, was the third son of the late Dr. John Bolton, of Mauritius, and was born in 1853.

After being educated privately, he entered the service of the predecessors of the Eastern Telegraph Company in 1869, going to Malta, where he remained till 1878, when he was appointed the Company's Superintendent at Salonica, whence he went to Trieste.

Mr. Bolton represented the Eastern Telegraph Company at the International Telegraphic Conference at Buda-Pesth some years back, and, but for his death, would have been present in a similar capacity at the Conference now being held in this country.

Mr. Bolton, who was a man of considerable ability and an accomplished linguist, was much esteemed by those with whom he came in contact.

He died at Trieste on the 8th of January, 1903, leaving behind him a widow (having married a Swiss lady, Miss Zoller, of Frauenfeld, Canton Thurgau) and three children.

Mr. Bolton was elected an Associate on the 12th of December, 1877, and was transferred to the class of Members on the 8th of November, 1883. G. A. B.

EDWARD TREMLETT CARTER, the Editor-in-Chief of the *Electrician*, was born in Calcutta in 1866, and was the eldest of ten surviving children. He was brought to England at an early age, and was educated privately at Bristol, afterwards at the Merchant Venturers' College in that city, and finally at the Bristol University College, where he went through the Engineering and Physics courses under Professor Hele Shaw and Professor Silvanus P. Thompson. Mr. Carter was for a short time demonstrator at the Bristol University College until he obtained an appointment at the School of Electrical Engineering and Submarine Telegraphy, Hanover Square, as assistant to the late Mr. Lant Carpenter, who was then principal. He was afterwards one of the

lecturers at this school, where he organised several courses of lectures and practical training in mechanical engineering, machine design, and other branches of engineering, one of which formed the basis of a series of articles orginally published in the *Electrician* on "Motive Power and Gearing for Electrical Machinery"; these articles were subsequently collected, revised, and issued in book form.

During this period of his career Mr. Carter was a frequent contributor to the technical press, and also carried on a small practice as consulting engineer.

On the closing of the School of Electrical Engineering in 1893, Mr. Carter joined the permanent staff of the *Electrician*, of which Mr. A. P. Trotter was then editor, and, on Mr. Trotter's retirement in 1895, he was appointed assistant-editor under Mr. W. G. Bond as editor. In 1897 Mr. Carter went over to Montreal to attend the meeting of the British Association for the *Electrician*, and afterwards made a prolonged tour in Canada and the United States. Shortly after his return he succeeded Mr. Bond as editor-in-chief.

Mr. Carter invented several things in connection with engineering, for some of which he took out patents; he also, in the intervals of his professional duties, indulged himself in the writing of fiction, several of his shorter stories being published in magazines, and one, at least, in book form; he was also very fond of music.

Mr. Carter had never a strong constitution, and in the winter of 1899, after a severe attack of pleurisy and bronchitis, following after influenza, had to leave his work and make a two months' tour to the Mediterranean and Egypt; this set him up again temporarily, but unfortunately the improvement in his health was not permanent. Last October it was found that his lungs were badly affected, and he went to a sanatorium to follow the "open-air cure." Unfortunately the insidious disease had taken too great a hold on his never strong constitution, and he succumbed to it on April 16th, aged 37 years, at Clevedon in Somerset, where he was devotedly nursed by his wife, having left the sanatorium when it was seen that the treatment was not benefiting him. Mr. Carter's loss will be deeply felt by his friends, for he had a most lovable nature, as well as by his widow and three sons.

Mr. Carter was elected an Associate of the Institution on the 23rd of February, 1888, and was transferred to the class of Members on the 23rd of May, 1895; he was also a member of the Société des Ingénieurs Civils de France, a Fellow of the Royal Astronomical Society, and of the Physical Society of London. F. C. R.

FRANCIS T. BRISTOW DANIELL, the son of Captain Daniell, an Indian artillery officer who was killed in the Mutiny, was born on the 25th of July, 1838, was educated at a private school in England, and went out to India as a Morse instructor under Sir W.. O'Shaughnessy. He was transferred to the Mehran Coast as inspector about the year 1862, and afterwards to Persia in 1863, where he assisted in the erection of the Persian lines. On the completion of this work he was appointed traffic manager. On the reorganisation of the Indo-European

Telegraph Department in 1887 he became superintendent, a position which he retained until, in August, 1891, he retired on a pension. He died at Brussels on the 17th of April, 1903.

Mr. Daniell was elected an Associate on the 27th of November, 1872, and was transferred to the class of Members on the 24th of February, 1875.

BERTRAM ANNANDALE GIUSEPPI was born on January 27th, 1872, and educated at Kensington Grammar School and King's College. He joined the Electrical Standardising Testing and Training Institution, at Faraday House, in 1890, to gain a technical training in electrical engineering, for which he had in early life exhibited a marked ability.

In 1891 he entered the works of Messrs. S. Z. de Ferranti, Limited, leaving again in 1892 to join the staff of the British Insulated Wire Company, Limited, with whom he was connected until 1901. Mr. Giuseppi then joined the staff of the South Lancashire Electric Traction and Power Company, Limited, as second engineer, and held this post at the time of his decease. His health had been bad for a number of years, and on June 23rd, 1902, he left his rooms in the morning to proceed to business, but not feeling well on the way, returned home, and died immediately.

Mr. Giuseppi joined the staff of the British Insulated Wire Company in its earliest days, and took a prominent part in the organisation of the factory, in the experiments for the determination of the properties of paper-insulated cables, and in the laying down and early working of the Prescot and District Electric Supply Works, one of the earliest provincial stations to be established for the sale of electric energy.

He subsequently carried out many important works for the British Insulated Wire Company, among them being the laying of high-pressure cables in Malta and Buenos Ayres, being engaged in the latter place for nearly two years.

Mr. Giuseppi played a prominent and most successful part in the difficult negotiations with the many local authorities through whose districts the lines of the South Lancashire Tramways run. It was, however, as an engineer that his abilities were particularly marked, and although he was still a young man at the time of his death, the Industry has undoubtedly lost a member of considerable experience and exceptional technical knowledge.

He was elected a Student on the 19th of February, 1891, transferred to the class of Associates on the 27th of January, 1893, and again to the class of Associate Members on the 8th of March, 1900. G. H. N.

JOHN HALL GLADSTONE was born on the 7th of March, 1827, and was educated at home. He studied chemistry at University College, London, under Graham, and at Giessen under Liebig, taking his Ph.D. degree in 1848. On returning to England, he lectured on chemistry at St. Thomas's Hospital from 1850 to 1852. His subsequent scientific research work was done in his own private laboratory, with the exception of the three years 1874 to 1877, when he held the Fullerian Professorship of Chemistry at the Royal Institution. Quite early he

was attracted by problems arising out of the composition and action of explosives, and investigated fulminic acid, iodide of nitrogen, gun-cotton, and xyloidine. In consequence of this work he was made a member of the Gun-cotton Committee appointed by the War Office, 1864–1868.

Even earlier—1859–1862—he had become a member of a Royal Commission on lighthouses, buoys, and beacons, writing the greater part of the Report and a good deal of the Appendix.

His original work in physics and physical chemistry was very fruitful. In 1897 he had written seventy-six papers himself, and forty-seven in conjunction with other workers. A paper on Chemical Affinity occupies forty-five pages of the *Philosophical Transactions of the Royal Society* for 1855. A long series of papers (with Mr. Tribe) on the copper-zinc couple and its applications conferred a distinct boon on organic chemistry. The chemistry of secondary batteries was first made known by Dr. Gladstone and Mr. Tribe, physical causes for their varying E.M.F. being subsequently investigated in conjunction with Mr. Hibbert.

In optics and chemical optics Dr. Gladstone's investigations led to a "law" which is constantly being used at the present time. It deals with the relations between the refractive index of a body and its density, and the general results will have to be considered in reference to corresponding changes in the dielectric constant. By prolonged researches he obtained consistent values for the refractive equivalents of the elements, and provided data of much value in certain optical problems.

A glance at the index to Ostwald's *Lehrbuch* will show how much Dr. Gladstone had to do with laying the foundations of physical chemistry. He was awarded the Davy Medal by the Royal Society, 1897.

Dr. Gladstone held many offices. He was the first President of the Physical Society, 1874–1876, and President of the Chemical Society, 1877–1879. He was elected a Fellow of the Royal Society in 1853, and served on the Council for many years. A member of the British Association from 1849 onwards, he served on the committee of Section B. for fifty years, and was president of the Section in 1872 and in 1883.

Dr. Gladstone had other and strong interests beside science. He served for twenty-one years on the London School Board. Here also he was a pioneer. When he began to advocate science teaching as a part of the ordinary day-school work, there were not so many sympathetic listeners as at the present day. In committee work he was most assiduous, and only those who were familiar with him could appreciate his daily contribution to the cause of reformed popular education. Besides this, there was much philanthropic work hidden from the public. An abiding support of broad and helpful religion was a most striking feature in his character.

Dr. Gladstone was twice married, first in 1852 to May, daughter of the late Charles Tilt, and secondly to Margaret, daughter of the late Rev. D. King, niece of Lord Kelvin.

He was elected a Member of the Society of Telegraph Engineers, now the Institution of Electrical Engineers, on the 11th of December,

1872. In 1887 he was elected a Member of Council, and in 1892, in conjunction with Mr. W. Hibbert, contributed a paper "On the Cause of the Changes of Electromotive Force in Secondary Batteries," read before the Institution on the 12th of May, 1892, and printed in the Journal, 1892, Vol. 21, p. 412. W. H.

HENRY THOMAS GOODENOUGH, late Electrical Engineer-in-Chief to the Great Western Railway Company, the service of which he entered on the 20th of May, 1863, as a lad clerk at the age of sixteen.

By assiduity and careful attention to his duties he was, in November, 1864, appointed travelling or instructing clerk. On the 14th of February, 1866, he was transferred to the Superintendent's office at Paddington; and on the 11th of August, 1888, when this Company by amalgamations with the South Wales, South Devon, Cornwall, and other smaller lines of railway reached a mileage of 2,600 miles, he was appointed Divisional Electrical Engineer for the northern division of this railway.

On the 1st of August, 1892, on the retirement of Mr. Spagnoletti, he was appointed to succeed him as Chief Electrical Engineer to the Company.

He was not constitutionally a strong man, and he was taken ill in the beginning of April, 1903, and after a short illness he died on the 15th of April, of "general peritonitis," at his residence at Slough.

He is very deeply regretted by his family, friends, and colleagues, and by his death the Great Western Railway Company has lost a zealous, conscientious, and anxious officer.

He was elected a Member on the 11th of February, 1886.

C. E. S.

ADOLPHUS GRAVES, Telegraph Superintendent of the North Eastern Railway, died at his residence at York, on the 19th of January, 1903, at the comparatively early age of 64 years. Entering the service of the Electric and International Telegraph Company in 1852, Mr. Graves had almost completed his Jubilee in the telegraph service when an attack of paralysis necessitated his retirement in October, 1902.

On the acquirement of the telegraphs by the State in 1870, the railway companies, who were even at that date probably the most extensive users of the telegraph, were left free to provide and maintain their own lines, and Mr. Graves was appointed to the post of Telegraph Superintendent by the Directors of the North Eastern Railway, with his headquarters at York. The appointment involved the creation of a new department of the railway service, and Mr. Graves' organising abilities rendered him particularly fitted for the task.

Dating from the time of Mr. Graves' appointment, railway telegraphy was destined to great development. Attention was being largely directed to the question of the safe operation of railways, and almost the first thing Mr. Graves was called upon to do in his new position was to install the block-system throughout the North Eastern system. Naturally, so large an extension of the service involved heavy work for the chief executive officer, complete reorganisation and a considerable

increase of staff. Further work of a similar character was necessitated later by the absorption by the North Eastern of other lines such as the Stockton and Darlington, the Blyth and Tyne, and others which, combined, now make up one of the most important railways in the kingdom. The system of block-working established by Mr. Graves—the 3-wire, single needle system—is still in use throughout the line, and it is indicative of the soundness of his judgment that the system and apparatus decided upon then is now more extensively used than any other for block signalling.

The introduction of the telephone at a little later period led to a further development of Mr. Graves' department. The very large use made of the telephone for traffic arrangements necessitated the erection of numerous lines in all parts of the system, and most careful supervision of circuit arrangements in order to produce the best results from a service point of view. It is probable that the introduction of the telephone involved even more consideration on the part of a conscientious executive officer than the establishment of the block system, since, whilst the latter followed regular and well-defined routes, the former had to be taken to all kinds of out-of-the-way places, and required the greatest possible care in order to prevent overlapping without restricting use.

Still later, in 1891, the North Eastern Railway introduced the electric light in their Hotel and offices at York, and Mr. Graves took charge of the plant, and of all further extensions, and he retained this branch of electric work until within about 15 months of his retirement. During this time plants for which he was responsible were laid down at Tyne Dock, Blyth, and Middlesbrough, and the original station at York was remodelled and finally removed to a new site. Electric light was installed at many other points on the North Eastern Railway during Mr. Graves' supervision, supply being taken from local public mains. At the time Mr. Graves relinquished this work, the consumption of electrical energy by the North Eastern Railway Company was considerably over a million units per annum.

At an early period Mr. Graves became impressed with the advantages that copper-wire possessed over iron-wire for overhead construction under certain circumstances. In the neighbourhood of large towns where space is scarce and railway telegraph lines converge, the large number of wires made it difficult to construct satisfactory lines, from a mechanical standpoint, if iron wires of the usual gauge were used. Moreover, the deteroriation of iron-wire was very rapid in the neighbourhood of large works, such as were established at many points on the North Eastern system. For these reasons Mr. Graves was led to experiment with copper as a substitute for iron in such places, and he was more than satisfied with the results obtained, and consistently advocated its use under similar conditions. Some misapprehension arose a few years ago with reference to the extent of Mr. Graves' claims, but he himself never claimed more than is here indicated.

Mr. Graves was of a modest and retiring disposition, and possessed of a most equal temperament. His chief characteristics were his capacity for work, his untiring industry, and his entire devotion to the

interests of the great Company that he served for nearly 32 years. To the last he kept the whole of the work of his department in his own hands, and directed operations as at the beginning of his career. No detail was too trivial for his personal attention, and he never seemed to realise that the amount of work he put upon himself was greater than was desirable.

In his personal relations Mr. Graves was ever the most courteous of men, considerate and patient with wrong-doers of the minor order, and helpful to all his fellows. Up to the last two or three years of his life he was very active, and his figure was known to all classes of railwaymen from Berwick to Doncaster, and from Carlisle and the West Riding to the North Sea. Probably no other prominent official was so well known to men in remote parts of the line.

Mr. Graves was an original member of the Society of Telegraph Engineers, and, although he was of too retiring a disposition to take part in the discussions, or to appear publicly before it in any capacity, he always took a keen interest in its proceedings. J. P.

LEOPOLD WILLIAM HEATH was born in London, December 23rd, 1872. Educated at the Central Foundation School, Cowper Street, he entered, in October, 1889, as a day student at the City and Guilds' Technical College, Finsbury, in the Department of Electrical Engineering, and after two years of earnest study he was awarded the College Certificate. He was at once offered a Senior Studentship in the Department of Mechanical Engineering, under Professor John Perry, whom he assisted in several investigations, including one on the application of Spherical Harmonics to the distribution of magnetic field around a solenoid. In July, 1892, on the completion of this additional year of studies, he entered the service of the Galway Electric Lighting Company, and in April, 1894, joined the engineering staff of the Blackpool Corporation Electric Tramways. A year later he entered the service of Messrs. Veritys at their Manchester branch, and in 1898 was appointed by the same firm to be manager of one of the departments of their factory at Birmingham. In 1900 he returned to the service of the Galway Electric Co. as their manager, but after a few months he exchanged this post for an appointment as designing engineer under the British Thomson-Houston Co., an appointment which brought him back to London. He was in 1901 also appointed to be lecturer in Applied Mathematics at the Northampton Institute in Clerkenwell. Early in the summer of 1902 he left England to study certain new developments in the works of the General Electric Co. at Schenectady, N.Y., and there on July 3rd, 1902, he met his death by electric shock through a defective switch in the laboratory. His untimely death cut short a very promising career. He had the capacity for great things; the patience of mind to watch for their development; and a sincerity and tenacity of purpose which gave assurance of success.

He was elected a Student on Feb. 11th, 1892; transferred to the class of Associates on May 8th, 1894, and to the class of Associate Members on Feb. 9th, 1899. S. P. T.

GEORGE ROBERT MOCKRIDGE was born at Bristol in 1854, and entered upon his telegraphic career in 1869. Five years later he joined the service of the Direct United States Cable Company, and served them successively in Torbay, Nova Scotia, Rye Beach, New Hampshire, and Boston, Massachusetts. In June, 1881, he resigned his appointment with that Company to take up the superintendency of the Penzance station of the Western Union Company. Here he remained until the time of his death, which occurred at Penzance in March, 1903, after an illness of a few weeks' duration. Of a robust constitution, his early death came as a great shock to the many friends that he had made in the course of an active life. His character was summed up as follows in an appreciative article from the pen of a colleague, written in the *Penzance Evening Tidings* of March 30, 1903: "Of a happy and optimistic disposition, true-hearted, open-handed and ever ready to help, conscientious in his dealings with his fellow-men, and in the best essentials a gentleman."

Mr. Mockridge was elected a Member of the Institution on the 23rd of January, 1896.

JAMES HENRY SECCOMBE, who died in 1902, at the early age of 35, received his early training in New York. From 1893 to 1896 he was with the Western Electric Company; then, for a twelvemonth, he served with the General Electric Company in New York, leaving them in 1897 to join the Sprague Electric Elevator Company. In 1898 he came to England on behalf of the last-named Company to assist in putting down electric-lift plant for the Central London Railway. When the railway was opened, Mr. Seccombe was taken over by the Railway Company as Electrician in charge of the lift equipment. His health, which had for some time been failing, gave way shortly afterwards, and he was compelled to take a long sea-voyage. Unfortunately, the rest and change had not the desired effect, and he died shortly after his return.

Mr. Seccombe was elected an Associate Member of the Institution on the 9th of January, 1902.

SIDNEY H. SHORT was born in Columbus, Ohio, U.S.A., in 1858, and received his early education in that city, afterwards passing in to the Ohio State University, where he graduated as a Bachelor of Science. During two years he was a teacher of Physics and Electrical Engineering in the University in which he graduated, and was afterwards, for five years, Professor of Physics and Chemistry in the University of Colorado.

In 1885 he began to work at the construction of electric apparatus and the equipment of electric railways. In 1889, in association with Mr. Brush, he formed and became President and Chief Engineer of, the Short Electric Railway Company of Ohio. He was also Chief Engineer of the Brush Electric Company of Cleveland, Ohio. In 1892 the Short Electric Company was merged in the General Electric Company of America, and Professor Short became a member of the Technical Board of this Company. In 1893, however, he left to take up the position of Vice-president and Chief Engineer of the Walker Company

of Cleveland, which manufacturing generators and motors of his design, rapidly developed, and was in 1898 absorbed by the Westinghouse Company. Professor Short then came to England, where he joined the English Manufacturing Company as Technical Director, and arranged for the erection of the Preston Works, which were soon in a position to commence work. All too soon afterwards he succumbed to an attack of appendicitis.

Professor Short was a prolific inventor, and was well known by his writings. His loss will be keenly felt not only by those who had the privilege of his friendship, but by many to whom he was known only by fame. He was elected a Member of the Institution on the 10th of January, 1901, and was a valued member of the Committee on Traction, Light and Power Distribution.

CARL FREDERIK TIETGEN, who died on the 19th of October, 1901, was born at Odense on the 19th of March, 1829. He was educated for the most part in England, and worked for some years in Manchester. Having returned to Copenhagen in 1855, he became a few years later the managing director of the *Privat Bank*, which was founded about that time.

He devoted much thought to submarine telegraphy and was actively associated in the work of the North Atlantic Telegraph Company, which was founded in March, 1866, to carry out his scheme for the establishment of telegraphic communication between the Northern part of Europe and America, *viâ* Iceland and Greenland, but the British Atlantic Cable was laid shortly afterwards, and the Danish Atlantic Cable was not proceeded with. Mr. Tietgen's attention was then devoted to the laying of cables between the Northern countries of Europe and this country, and in this work he was associated with Mr. H. G. Erichsen of Copenhagen, and Mr. J. Newall of Gateshead. Commencing in 1867, three companies were formed, the Danish-Norwegian-English Telegraph Company, the Danish-Russian Company, and the Norwegian-British Company. The first of these, with Mr. Tietgen as Chairman, laid a cable between Denmark and England, the second a cable between Denmark and Russia. The three companies, in 1869, amalgamated under the name of the Great Northern Telegraph Company of Copenhagen and, at that time, owned over 1,000 miles of cable. In 1870, Mr. Tietgen formed the Great Northern Telegraph China and Japan Extension Company, which was also merged in the Great Northern Telegraph Company.

He was Chairman of the latter company from the first up to 1897, when, owing to failing health, he found it necessary to retire from active duties. Even then, however, he did not sever his connection with the company, but accepted the position of Honorary Chairman.

Mr. Tietgen occupied a most distinguished position in Denmark, having been closely identified with the development of the country and of its enterprises; and in due time became a Privy Councillor. He also received the Grand Cross of the Order of the Dannebrog.

He was elected a Member of the Institution on the 29th of March, 1872.

CHARLES GRANVILLE VINES, born in 1873, was educated at Christchurch School, Oxford, and at Rossall. He served his apprenticeship, from 1890 to 1894, with Messrs. Robey and Co., of Lincoln, attending at the same time evening classes at the Lincoln School of Science and Art. He was subsequently employed by Messrs. Willans and Robinson, working in their outside department at the City of London Electric Light Company's works at Bankside.

In 1897 he went to South Africa, where he was engaged in engineering work at Belingwe and at Johannesburg.

In 1899 he went to Kimberley as manager of Mr. Reunert's electrical works. During the siege of Kimberley he served as a non-commissioned officer in the Veterans' Company of the Town Guard, having previously served as a volunteer while at school. On the completion of the electric light installation he was unanimously elected Borough Electrical Engineer by the Kimberley Town Council. And then, when his future seemed assured, he contracted typhoid fever and, after an illness of three weeks, died at Kimberley on the 28th of March, 1902, at the early age of twenty-nine.

He was elected an Associate Member of this Institution on the 10th of January, 1901, and was also an Associate Member of the Institution of Mechanical Engineers.

JAMES WIMSHURST, born on the 13th of April, 1832, was the son of Mr. Henry Wimshurst, who was the first successfully to apply the bladed screw propeller to steamships, and who designed, built, and owned the two first screw-propelled vessels, the *Archimedes* and the *Novelty*.

Mr. James Wimshurst was apprenticed to shipbuilding and engineering at the works of the late Mr. Joseph Mare, now the Thames Iron Works, Limited. Upon completion of apprenticeship he was appointed to the staff of Lloyds Registry of Shipping. After some years he left Lloyds to take up an appointment as Chief of the Staff of the Liverpool Underwriters Registry, and resigned this position, after ten years, to join the Board of Trade as Chief Shipwright Surveyor in the Consultative Department at Whitehall, a post from which he retired three years ago, shortly after reaching the age limit.

During the whole of his career Mr. Wimshurst had devoted the greater part of his leisure time to scientific and mechanical research, and in all houses in which he lived had fitted up large workshops, equipped with benches, lathes, and other tools driven by power, and it was there that he made with his own hands the various devices and apparatus which he invented and with which his name will always be associated. Whilst taking the keenest interest and closely following up the latest scientific and mechanical inventions of all kinds, the subject in which he mostly interested himself was very high-tension electricity, and for the last twenty years of his life he always had some dozen or twenty induction or influence machines of all sorts and kinds in his workshops to experiment upon.

In 1881 a description was published in *Engineering* of a new type of influence electrical machine, and, being interested, he immediately

made one from the written description, but not being contented wi h the results, he built an improved form of machine of the Carré type. Later he designed and built several machines of the Holtz type, but having the fixed plates supporting the armature cut of rectangular shape and differently coupled; both of these alterations were found greatly to increase the output, and to rectify the difficulty of getting mixed poles. Some of these machines were very large and powerful, and in their day exceeded all others in both efficiency and size. They were fully described in *Engineering* at the time, and are generally known as Wimshurst's Improved Holtz Machine.

Shortly after this, Mr. Wimshurst designed the well-known influence machine bearing his name, having two plates rotating in opposite directions, this type of machine being remarkable for the great output, the ease with which it excites itself, and its simplicity of construction. It would be difficult to overestimate the value of such a machine in the laboratory or the lecture theatre on account of its great reliability in exciting itself, and it is a matter of interest to note that Mr. Wimshurst hit upon the exact and right proportions in the design of his first machine, such as are found even to this day to be most efficient. His inventive nature led him to design many other forms of this same machine, having cylindrical plates, radial arms, or double coating with paraffin, double plates laid against each other on the same driving boss. All these were tried, but to no practical advantage, and were dropped.

It may be mentioned that the greatest regret and disappointment experienced lay in the fact that he did not patent the invention, and therefore had no control over the design and manufacture of the machines as he would have liked to have, not from a financial point of view, but merely to see that none but well-fitted and well-designed machines were made for sale, for his thoroughly sound engineering mind could not view with indifference much of the trashy and defective apparatus that he saw sold to the public. The best proportions having been ascertained, larger and larger machines were constructed. Then, after the discovery of the Röntgen-tube and X-rays, when applying a tube to the terminal of the machine, it was found to be fully illuminated, and a further field for research was thus opened out. The influence machine is found to be of great value for screen work, giving a steady light with considerable penetration, and with entire immunity from the very dangerous X-ray burns which are possible in using the heavy current from battery and coil.

Another highly important application of the Wimshurst machine is the production of exceedingly high-tension brush discharges, which are found to be very efficacious in the cure or reduction of lupus, rodent ulcer, cancer, and consumption. Most large hospitals are equipped with the Wimshurst machine, and in the United States, especially, the machine is used extensively.

Mr. Wimshurst throughout his career devoted his day hours to the business of shipbuilding and engineering, but the whole of his leisure he gave up to experimental research; nothing gave him greater pleasure than to work with and to entertain and help his scientific

friends in his workshops. He was a most original thinker, and was always at work designing apparatus, taking the greatest pleasure in endeavouring to test the truth of the various theories of the day. He was a Fellow of the Royal Society, a Member of Council of the Physical Society, Member of Council of the Röntgen Society, Member and one of the Managers of the Royal Institution, Member of the Institution of Naval Architects, Hon. Member of the Institution of Marine Engineers. He was exceedingly simple in his tastes and mode of living, most generous and hospitable, a good friend to a great number of young men whom it was his greatest pleasure to assist. His loss will be regretted by these and by his large circle of friends.

Mr. Wimshurst was elected a Member of the Institution of Electrical Engineers on the 10th of June, 1889. J. E. W.

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See also this volume, p. 834.

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"COMMUTATOR LOSSES," by W. B. HIRD, Member.
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MANCHESTER LOCAL SECTION.

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[*p*] signifies that the reference is to a subject incidentally introduced into a paper, and not necessarily indicated by the title.

[D] signifies that the reference is to remarks made in a Discussion upon a paper, of which the general title or subject is quoted.

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[Cape L.S.]	do.	do.	do.	of the Cape Town Local Section.
[Dub. L.S.]	do.	do.	do.	of the Dublin Local Section.
[Glas. L.S.]	do.	do.	do.	of the Glasgow Local Section.
[Leeds L. S.]	do.	do.	do.	of the Leeds Local Section.
[Man. L.S.]	do.	do.	do.	of the Manchester Local Section.
[Newc. L.S.]	do.	do.	do.	of the Newcastle Local Section.

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